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Evaluation of Secondary Environmental Impacts of Urban Runoff Pollution Control

Rexnord, Inc.
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EVALUATION OF SECONDARY ENVIRONMENTAL IMPACTS OF URBAN RUNOFF POLLUTION CONTROL

by

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16. ABSTRACT

This report presents a generalized evaluation of the impacts associated with different urban stormwater runoff (UR) treatment techniques. The report addresses the definition of the problem, estimates the volume and characteristics of the UR and the sludges expected, evaluates six methods of UR sludge treatment, and examines alternatives and impacts for UR treatment sludge handling such as bleed/pump-back to the dry-weather plant, and land disposal.

Regarding bleed/pump-back of UR sludges, solids deposition in sewers and overload to the dry-weather facilities are anticipated to cause problems.

The most cost-effective sludge treatment alternative appeared to be lime stabilization followed by thickening, pressure filter dewatering, and landfill disposal. Secondary impacts included costs, water quality, noise, energy consumption, air pollution, and land area requirements.

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FOREWORD

The U.S. Environmental Protection Agency was created because of increasing public and governmental concern about the dangers of pollution to the health and welfare of the American people. Noxious air, foul water, and spoiled land are tragic testimony to the deterioration of our natural environment. The complexity of that environment and the interplay between its components require a concentrated and integrated attack on the problem.

Research and development is that necessary first step in problem solution and it involves defining the problem, measuring its impact, and searching for solutions. The Municipal Environmental Research Laboratory develops new and improved technology and systems for the prevention, treatment, and management of wastewater and solid and hazardous waste pollutant discharges from municipal and community sources, for the preservation and treatment of public drinking water supplies and to minimize the adverse economic, social, health, and aesthetic effects of pollution. This publication is one of the products of that research; a most vital communications link between the researcher and the user community.

This study describes a generalized evaluation of the secondary environmental impacts associated with separate stormwater runoff (UR) pollution control techniques.

Francis T. Mayo
Director
Municipal Environmental Research
Laboratory

PREFACE

There is presently little doubt that stormwater runoff represents a significant source of water pollution. It bears importantly upon the quality of the nation's streams, estuaries, lakes and oceans.

Of particular concern has been urban surface runoff and its contributions to the deterioration of receiving water quality. In this regard, these pollutional effects of urban surface runoff may be the end-product of both direct and indirect contributions of contaminants. For example,

1. Direct pollutional contributions include those discharged in surface runoff from separate storm drainage collection systems. In this report, this surface runoff is limited to and defined as separate urban stormwater runoff (UR).
2. Indirect pollutional contributions include urban overflows due to planned or unplanned addition of stormwater to other wastewater flows. In this report, the overflow referred to is limited to the sewer overflow from combined sanitary and stormwater systems due to hydraulic overload and is designated as combined sewer overflow (CSO).

Urban stormwater management is a major problem in the field of water quality management. As a result, much research, development and demonstration of techniques for controlling and/or treatment of this source of pollution have been implemented. Moreover, great emphasis has been placed upon the primary impacts from urban runoff pollution control, and the secondary impacts have generally been neglected.

This study is concerned with the secondary environmental impacts of urban runoff pollution control techniques.

Representative complementary studies concerning CSO treatment sludges include, "Handling and Disposal of Sludges from Combined Sewer Overflow Treatment",

Phase I - Characterization - EPA-600/2-77-053a, May 1977
Phase II - Impact Assessment - EPA-600/2-77-053b, December 1977
Phase III - Treatability Studies - EPA-600/2-77-053c, December 1977

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ABSTRACT

This report presents a generalized evaluation of the impacts associated with different urban stormwater runoff pollution control techniques. The control techniques investigated included urban runoff (UR) treatment and streetsweeping practices.

The report addresses the definition of the problem, estimates the volume and characteristics of the UR and the sludges expected, evaluates six methods of UR sludge treatment, examines alternatives and impacts for UR treatment sludge handling such as bleed/pump-back to the dry-weather plant and land disposal and evaluates streetsweeping as a UR pollution control technique.

UR sludge volumes were estimated to range from 0.3 to 6.0 percent of the UR flow [2.9×10^9 m^3/year (7.7×10^5 M gal/year)] with total solids concentrations varying from 0.51 to 12 percent. For comparison, these national sludge characteristics were contrasted to those estimated for a portion of a calibrated drainage area in Milwaukee, Wisconsin. The extreme variation in UR typical suspended solids concentration (415 mg/l on a national basis and 156 mg/l on a site specific basis) was reflected in the sludge characteristics and associated handling costs. High grit contents and low volatile solids are anticipated in UR sludges. Nutrient levels are lower in UR sludges than either CSO or raw primary sludges.

Regarding bleed/pump-back of UR sludges, solids deposition in sewers and overload to the dry-weather facilities are anticipated to cause problems. Dry-weather sludge handling facilities would require 1.5 to 4.5 times additional capacity.

The most cost-effective sludge treatment alternative appeared to be lime stabilization followed by thickening, pressure filter dewatering and landfill disposal. Annual costs for UR sludge handling were shown to range from \$126 to \$252/ha (\$51 to \$102/acre) on a national basis. Secondary impacts in addition to costs included water quality, noise, energy consumption, air pollution and land area requirements.

This report covers a period from July 1977 to April 1978 and was submitted in partial fulfillment of Contract No. 68-03-2574 by the Environmental Research Center of Rexnord, Inc., under the sponsorship of the U.S. E P A.

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SECTION I

INTRODUCTION

When evaluating the impacts of methods to reduce pollution associated with urban stormwater runoff (UR) it is critical to include an in-depth assessment of the effects of handling the resulting sludge or solids residues. If UR treatment is implemented, the problems with the additional volumes of sludge can be quite significant. If other management techniques are utilized, there are still solids residuals which will require disposal. This report presents an overview of the problems associated with handling residuals from UR treatment or from various housekeeping practices. The evaluation is performed for typical national areas as well as for a well-defined drainage basin.

OBJECTIVES OF THE STUDY

The major objectives of this study are to:

1. Provide a general definition of the sludge handling program if UR treatment is implemented on a nationwide basis.

2. Evaluate the feasibility of various UR sludge handling options on a technical and/or economic basis.

3. Establish the land areas requirements anticipated for implementation of UR treatment and associated sludge handling.

4. Compare the effectiveness and costs of housekeeping techniques to end of the pipe UR treatment and sludge handling.

The overall purpose was therefore to roughly quantify the secondary impacts associated with UR management options in the United States.

LIMITATIONS OF THE STUDY

It must be emphasized that this evaluation was performed to provide a generalized quantification of the problems associated with handling UR treatment residuals. Sludge quantity and quality were not obtained from studies but were extrapolated from available data regarding combined sewer overflow sludges. The project effort was limited to this approach since it was felt that the extreme variabilities or UR quality would preclude an accurate nationwide assessment. It is anticipated that UR sludges must be evaluated on a site-specific basis for accurate quantification, so a detailed national review is not required. However, it must be emphasized that the data presented should not be used for design, but is intended to alert the reader to the magnitude of the potential problems associated with UR sludge handling.

Another consideration is that an in-depth evaluation of the impacts associated with UR treatment is not included. Some information is presented for comparison to streetsweeping techniques, but it is not detailed. The reader is encouraged to review other literature for specific information on UR treatment systems (1,2).

APPROACH AND ORGANIZATION OF THE REPORT

The main emphasis in this report has been on the evaluation of the impacts associated with handling the sludges generated from proposed UR treatment. Because of the difficulty in defining UR quality on a national basis, a dual approach has been utilized. National UR sludges were characterized based on published average data. These were compared to sludges associated with a specific monitored urban drainage area to illustrate the differences in impacts and to emphasize the need to define each site individually.

The various methods for handling sludges from UR treatment were then investigated. Since satellite treatment of the sludges is most feasible on a generalized basis, this alternative was given the most emphasis (11). However, the high costs associated with the sludge handling as well as the area needs for the treatment processes, indicated that use of other control alternatives, such as streetsweeping, may be beneficial.

Throughout the evaluation, both primary and secondary environmental impacts were considered. Primary impacts can be defined as "those that can be attributed directly to the proposed action" (3). For the purpose of this report they are considered to be water quality, cost and land area requirements. Secondary impacts are more difficult to quantify since they are considered "indirect or direct changes" (3). The general approach is that the environmental effects can be related to "induced changes in the pattern of land use, population density, and related effects on air and water quality or other natural resources" (3). Since these criteria are most directly related to facilities construction, the main secondary impacts for this report are those effects on air and water quality. Energy consumption was also considered in this category.

REPORT FORMAT

The report has been divided into 9 main sections. Sections 2 and 3 present the conclusions and recommendations associated with the study. Section 4 summarizes the primary and secondary impacts of the various handling techniques. The body of the report is presented in Section 5 - 9. Section 5 defines the magnitude of the problems and quantifies the volumes and characteristics of anticipated UR sludges. Section 6 considers the alternative of bleed/pump-back of treatment sludges to the dry-weather plant. The primary and secondary impacts of handling UR sludges at a satellite site are included in Section 7. The disposal of storm generated sludges on land is addressed in Section 8 .

SECTION 2

CONCLUSIONS

DEFINITION OF THE PROBLEM

1. An average volume of UR on a nationwide basis was calculated to be 2.9 x 10^9 m^3/year (7.7 x 10^5 M gal/year). The associated sludge volumes were assumed or calculated to range from 0.3 to 6.0 percent of the influent flow depending upon the treatment used and the sludge handling techniques employed.

2. The UR quality directly impacted the associated sludge characteristics. The selected national average for suspended solids concentration (415 mg/l) greatly exceeded the previously verified STORM model predicted value for a part of the Milwaukee River Basin area in Wisconsin (156 mg/l) established in a previous project (8). As a result, sludge quantities and qualities for the two areas were extremely different.

3. Storage volume requirements were evaluated for five-year and one-year design storms at one-hour and 24-hour durations. Total pumpout times of 24 and 48 hours were considered. The type and duration of the design storm, pumpout rates, and rainfall significantly affected the storage required. The nationwide evaluation indicated that storage volumes of 81 to 224 m^3/ha (1160 to 3200 ft^3/acre) were needed compared to 67 to 197 m^3/ha (954 to 2820 ft^3/acre) for the Milwaukee River Basin.

4. Land area needs are dependent upon the type of storage technique employed, the basin volume and depth, and the pump-out rate. Assuming a 4.75 m (15 ft) basin depth, national storage area requirements ranged from 0.18 to 0.56 percent of the area served by storm sewers and 0.31 to 0.44 percent for the Milwaukee River Basin.

5. Sludge quantities and qualities were extrapolated based on published removal efficiencies and similarities to combined sewer overflow (CSO) sludges. Percent solids in the UR sludges were calculated to range from 0.51 to 12 percent depending upon the treatment used and the sludge handling techniques employed.

6. Since storage/sedimentation was evaluated for total capture and twenty-four hour detention, solids removal efficiencies were high (87 percent). A flow-through mode of operation would significantly reduce the effectiveness of the treatment methods.

7. The quality of sludges generated by UR treatment varied significantly for the national and Milwaukee River Basin areas evaluated. The greatest differences were present in the sludge solids concentrations with the national values approximately three times greater than those calculated for Milwaukee. Conversely, BOD_5 concentrations were greater in the Milwaukee UR sludges. These differences and others reflect the variation in UR qualities used in the calculations.

8. Nationwide, UR sludge volumes range from 8.78×10^6 to 175×10^6 m^3/yr (2.3×10^3 to 46.2×10^3 M gal/yr) compared to 156×10^6 m^3/yr (41.2×10^3 M gal/yr) for CSO sludge and 60.9×10^6 m^3/yr (16.1×10^3 M gal/yr) for raw primary sludge. Annual dry solids weights for UR sludges [7.46×10^6 metric tons (8.22×10^6 tons)] also exceed calculated amounts for CSO sludge [1.67×10^6 metric tons (1.84×10^6 tons)] and raw primary sludges [2.88×10^6 metric tons (3.18×10^6 tons)].

9. UR sludge nutrient concentrations range from 502 to 1270 mg/kg total phosphorus as P and 1,140 to 3,370 mg/kg TKN. These amounts are consistently lower than nutrients found in CSO sludges (2,800 to 7,400 mg/kg - P and 1,100 to 13,000 mg/kg TKN) and raw primary sludges (3,500 to 12,200 mg/kg -P and 15,000 to 40,000 mg/kg TKN).

10. Differences in other parameters including metals and BOD_5 were inconclusive given the range of removal efficiencies and source variations.

11. Due to the intermittent nature of UR sludge generation and the sources of the runoff, grit concentrations are anticipated to be high and volatile solids concentrations are expected to be low. These characteristics are expected to adversely affect operation of many treatment processes.

IMPACTS OF BLEED/PUMP-BACK OF URBAN RUNOFF SLUDGES

12. The problems associated with bleed/pump-back of UR sludges are similar to those evaluated with regard to CSO sludges.

13. It is anticipated that bleed/pump-back of UR sludges may adversely affect operation of the dry-weather plant due to sludge age, high grit and low volatile solids content.

14. Solids deposition in gravity flow sewers is anticipated to be a severe problem with regard to bleed/pump-back of UR sludges.

15. Depending on the degree of capacity available at the dry-weather plant, bleed/pump-back can cause overloads with respect to solids loadings.

16. Specifically, the solids overload caused by bleed/pump-back to the dry-weather plant detrimentally affects the primary and final

clarifiers as well as those sludge handling facilities whose design is based on solids loading such as thickeners, digesters, filters, centrifuges, etc.

17. The weight of solids associated with bleed/pump-back can be shown using population equivalents to represent service to an additional 224,000 to 316,000 people in a dry-weather plant area serving 340,000 persons.

18. There does not appear to be any toxicity impact on the dry-weather plant due to bleed/pump-back of UR sludges when the sludge is mixed with dry-weather influent flow.

19. The increased solids from bleed/pump-back of UR sludges will substantially overload sludge handling processes based on solids loading and require 1.5 to 4.5 times additional capacity.

20. Bleed/pump-back of the dewatering residuals generated from satellite treatment plant dewatering does not appear to cause significant overloading to the dry-weather plant or associated sludge handling facilities.

21. Secondary impacts from bleed/pump-back are associated with transportation to the dry-weather plant or to the disposal site. Nuisance problems, air and noise pollution and increased energy consumption are anticipated. Disposal secondary impacts involve all those associated with any dry-weather plant disposal technique with increases proportional to increases in sludge volumes (18 to 25 percent)

IMPACTS ASSOCIATED WITH URBAN RUNOFF SLUDGE HANDLING AT SATELLITE TREATMENT FACILITIES

22. Review of available sludge handling processes indicated that the most applicable processes for UR sludge handling are: gravity thickening, lime stablIization and vacuum filter or filter press dewatering. Truck transport followed by landfill or landspreading disposal were considered appropriate.

23. Due to the low nutrient content anticipated in UR sludges, landspreading is considered a disposal option, rather than a resource recovery method.

24. Landspreading rates are limited by the cadmium content in sludges. Loading rates range from 26.9 metric ton/ha (12 ton/acre) on a national basis to 33.6 to 62.7 metric ton/ha (15 to 28 ton/acre) for the Milwaukee River Basin sludge. Site life is 40 years.

25. Six UR treatment sludge handling schemes were evaluated for three national UR areas and the Milwaukee River Basin area. These were:

a. Lime Stabilization → Gravity Thickening → Vacuum Filtration → Landspreading.

b. Lime Stabilization → Gravity Thickening → Vacuum Filtration → Landfill.

c. Lime Stabilization → Gravity Thickening → Pressure Filtration → Landspreading.

d. Lime Stabilization → Gravity Thickening → Pressure Filtration → Landfill.

e. Lime Stabilization → Gravity Thickening → Landspreading.

f. Lime Stabilization → Landspreading.

The sludge handling scheme involving lime stabilization, gravity thickening, pressure filtration dewatering and landfill disposal was most cost-effective.

26. Capital and annual costs associated with disposal of sludges from the Milwaukee area were less than those calculated for national areas because of the lesser weight of solids generated per unit area in Milwaukee.

27. Annual costs, including operating costs and amortized capital costs, range from \$126.25 to \$251.21/ha (\$51.13 to \$101.74/acre) on the national level and \$52.37 to \$112.59/ha (\$21.21 to \$45.60/acre) for Milwaukee.

28. The only UR and sludge handling alternative found to be completely inappropriate on a cost basis was swirl concentration treatment without sludge thickening followed by landspreading disposal.

29. Total capital costs for sludge handling methods ranged from \$365 to \$1390/ha (\$148 to \$563/acre) on a national level. Milwaukee River Basin capital costs were again substantially lower, ranging from \$168 to \$743/ha (\$68 to \$301/acre).

30. Land area needs for sludge handling were quite small. If storage sedimentation is involved, the processes can be located above the covered basin, eliminating the need for additional area. Swirl concentration land area needs involve only sludge handling and range from 0.41 to 0.47 m^2/ha (1.80 to 2.07 ft^2/acre) on a national basis; 0.22 to 0.45 m^2/ha (0.94 to 1.97 ft^2/acre) for Milwaukee.

31. Secondary impacts can be associated with the treatment system, transportation mode, and the disposal site. Evaluation of these must be performed on a site-specific basis. The potential impacts can only be identified on a general level.

32. Treatment system impacts include nuisance associated with odor from stored sludge, reduction in area availability, increases in noise levels, and energy consumption.

33. Transportation causes increase in noise and air pollution from travel over dusty roads and emissions. Energy uses are also greater.

34. Disposal secondary impacts are most significant. They include those associated with surface or ground-water contamination, increased use of available disposal area, higher instances of vectors, noise and air pollution, or impact on sensitive/unique areas. Proper operation of disposal sites should minimize these problems.

LAND DISPOSAL OF STORM GENERATED SLUDGES

35. It is felt that wet-weather flow sludges can be incorporated into EPA sludge land disposal programs. There are problems associated with this incorporation which are not insurmountable.

36. The quantity of UR and CSO sludges requiring disposal is at least about the same magnitude as that of dry-weather sludge.

Sludge	Annual Sludge Volume 10^6 m^3	Annual Sludge Volume 10^9 gal.	Average Percentage Solids
Dry weather (2)	125.0	33.0	2 - 3
CSO (3)	157.0	41.5	0.3-6
UR (Table 21)	8.8-175.0	2.3-45.5	0.5-12

Therefore, a significant amount of additional land will be required for land utilization of wet-weather sludges over that needed for dry-weather sludge.

37. Dry-weather and UR sludges are distributed relatively uniformly over the U.S. In contrast, CSO sludges are concentrated in the Northeast and Great Lakes regions of the country (3). Therefore, separate or codisposal of dry- and wet-weather sludges will be a more formidable problem in the Northeast and Great Lakes regions of the U.S.

38. Dry-weather sludge is considered a low grade fertilizer based on nutrient content. UR and CSO sludges in comparison may be considered lower grade fertilizers.

39. Land utilization of wet-weather sludges may be accomplished by land application or landfilling. Design criteria are available for each method.

40. Sludge application rates are appreciably greater for landfilling disposal than for land application.

41. It is indicated that disposal of liquid wet-weather sludges on land will see limited use because the relatively low (<15%) solids concentration is not applicable to wet soils during or immediately after heavy rainfall and is cost-effective only for short distances [8 to 16 km (5 to 10 miles)] from the treatment site. Therefore, wet-weather sludges generated will have to be pretreated prior to disposal by land utilization.

42. It is indicated that the most applicable pretreatment processes for handling wet-weather sludges for land disposal are storage, thickening, lime stabilization and filtration dewatering.

43. Although costs for land utilization of wet-weather sludges have been estimated, these costs should be used only for preliminary work as actual costs may vary considerably with specific local conditions.

SUMMARY OF IMPACTS

- Pollutants are more efficiently removed by treatment processes than by streetsweeping because both off-street and on-street contaminants are contained in runoff. The exact amounts removed vary with the parameter and the treatment or streetsweeping technique.

- Pollutant loadings contributed by UR on a national level have comparable suspended solids amounts to CSO and exceed loadings from treated secondary effluents by approximately a factor of three. BOD_5 and nutrient loadings from UR are significantly lower than either CSO or treated secondary effluent.

- Calculated loadings from UR and other sources in the Milwaukee River Basin indicated lower solids loadings and more direct effects from CSO.

- Disposal costs were shown to increase the annual costs by 6 to 80 percent depending on the management techniques. Streetsweeping disposal costs were much lower than UR sludge disposal costs because the materials have a higher specific gravity and are handled on a dry basis.

- Calculated annual costs (operating and maintenance plus amortized capital costs) including treatment and disposal range from $343 to $543/ha ($139 to $220/acre) for swirl concentration treatment, $2351 to $2504/ha ($952 to $1,014/acre) for sedimentation treatment, and $25 to $131/ha ($10 to $53/acre) for streetsweeping practices. Milwaukee treatment costs were lower due to the lower influent UR suspended solids concentrations.

- Urban land area needs are greatest for storage/sedimentation systems. Availability of land is difficult to define on a national basis and use of land for UR storage or treatment may result in public objections.

- Disposal sites are more rapidly filled when UR management residuals are co-disposed with dry-weather sludges. UR sludges can add 15 to 20 percent area needs but streetsweepings add appreciably less.

- Secondary impacts comparisons between alternative management procedures are difficult to perform since generalized quantification is not possible.

SECTION 3

RECOMMENDATIONS

1. The quantity of UR sludges should be defined through on-site testing to determine if the actual qualities are similar to those predicted in this report.

2. Associated water quality impacts after streetsweeping and UR treatment should be evaluated in more detail to provide needed justification for implementing management procedures.

3. Actual removal efficiencies for storage/sedimentation treatment over extended treatment periods should be verified on a large scale.

4. Swirl concentration treatment removal efficiencies for nitrogen and phosphorus should be established by on-site testing.

5. Secondary impacts associated with disposal techniques should be evaluated. Leachate qualities from UR sludge or streetsweepings should be established by lysimeter or other appropriate testing.

6. Land area availability in densely populated city areas should be compiled on a nationwide level.

7. A user's manual or handbook should be prepared which is similar in nature to those prepared for land utilization of domestic sludges but specific to the land utilization of wet-weather sludges (UR and CSO).

   The contents of the document should detail the principles and design criteria for disposal of UR and CSO sludges by land application and landfilling. A suggested outline of the contents of the manual is presented below:

   A. Land Application of Wet-Weather Sludges

      1) Introduction

      2) Preliminary Planning

         a. Obtain local support
         b. Basic data collection

            1. Sludge characteristics
            2. Sampling and analysis

         c. Climate

        - d. Regulations
            - 1. Local and State
            - 2. Federal
    - 3) Site Selection
        - a. Preliminary screening
        - b. Site identification
        - c. Topography
        - d. Soils
        - e. Geology
        - f. Site delineation and evaluation
        - g. Site acquisition
    - 4) Process Design
        - a. Agricultural lands
        - b. Forested lands
        - c. Other non-agricultural users
    - 5) Facilities Design
        - a. Detailed site investigation
        - b. Preapplication treatment
        - c. Transportation of sludge
        - d. Application methods
    - 6) Management and Monitoring
        - a. Management
        - b. Site access control
        - c. Scheduling
        - d. Monitoring
    - 7) Costs
        - a. Transportation
        - b. Preapplication treatment
        - c. Spreading
    - 8) Design Examples

8. Pilot scale testing should be performed to ensure that an operation for the land utilization of wet-weather sludges based upon the criteria developed will function properly for a given sludge and site.

   The pilot-scale system may be comprised of the following process elements;

    - a. Storage
    - b. Lime stablization
    - c. Thickening
    - d. Filtration dewatering
    - e. Disposal by land utilization

SECTION 4

SUMMARY OF IMPACTS

The remainder of this report presents a detailed evaluation of primary and secondary impacts associated with handling sludges generated by UR treatment and with implementing various streetsweeping procedures. This section briefly summarizes and compares the impact associated with both of these procedures without addressing the calculation approach which was utilized.

METHODOLOGY OF IMPACT EVALUATION

The basic methodology applied throughout this report involved calculation of generalized impacts for three different nationwide storm-sewered areas and a more specific evaluation for a real city area; in this case, the Milwaukee River Basin. UR treatment sludge volumes and characteristics for both nationwide and Milwaukee areas were based on UR quality and assumed percent removals for different treatment processes. Estimates for area requirements were based on general loading rates and available equipment sizes. Streetsweeping effectiveness was estimated from available references and then extrapolated to the size of the areas being studied. All assumptions utilized in the calculations are presented in detail in the appropriate section of the report.

PRIMARY IMPACTS

The three direct impacts of concern in this report are the water quality impacts, the costs for treatment and the land area requirements for the different UR management options.

Water Quality Impacts

The major positive environmental impact associated with implementing any type of UR management technique is the reduction in loadings to the receiving water. This reduction shall generally result in an improvement in the receiving water quality. The annual removals of various pollutant parameters can be compared to indicate, in a general sense, the positive impacts of UR management procedures on actual water quality. Table 1 presents annual removals of several parameters for the various UR management procedures discussed in this report.

These data show that treatment of UR is more effective in removing the selected pollutants than streetsweeping. This conclusion appears to be conservative and understated for several reasons.

1. The streetsweeping frequency of seven days used in developing the streetsweeping data in Table 1 is higher than that typically used in practice. Typical street cleaning frequencies are once or twice a month (55).

2. The streetsweeping data developed in Table 1 were based on streets with essentially no parked vehicles. Vehicles parked along a street cleaning route reduce the length of curb that may be cleaned. Therefore, parked vehicles will significantly reduce the cleaning effectiveness of normal cleaning programs. It also follows that special parking regulations may be necessary to improve street cleaning operations.

TABLE 1. COMPARISON OF ANNUAL POLLUTANT REMOVALS

	Pollutant removals, lb/acre/year			
	Treatment		Streetsweeping (52 passes/year)	
Parameter	Sedimentation	Swirl conc.	Good street conditions	Poor street conditions
National				
Suspended solids	1297	894	102	346
BOD$_5$	35.9	35.9	-	-
COD	-	-	11.9	35.5
Nitrogen	4.32	2.26	0.21	0.21
Phosphorus	0.87	0.90	0.005	0.014

Metric conversion:
lb/acre/year x 1.121 = kg/ha/year

Moreover, it may have been expected that treatment of UR will remove more contaminants than streetsweeping because treatment has the opportunity to remove contaminants from off-street sources as well as from on-street sources which are both contained in the runoff.

It is recognized that more frequent street cleaning than that used as a basis in Table 1 will increase street contaminant removal. However, the logistics of implementing a higher program frequency, especially for a large urban area, could be staggering. For example, frequent street cleaning on smooth asphalt streets (once or twice per day) would be needed to remove up to 50 percent of the total solids and heavy metal yields of UR. Furthermore, it is estimated that a cost increase of about tenfold over typical street cleaning program costs may be necessary to realize substantial improvements in UR quality (greater than 25 percent of total solids and heavy metals) (55).

It has also been shown (55) that organics and nutrients in the UR cannot be effectively controlled by intensive street cleaning. Typically much less than 10 percent removal results even with daily cleaning.

The impact on receiving waters after implementing UR management procedures is difficult to estimate on a general basis. The type of receiving water as well as the relative magnitude of other urban loadings must be taken into account when assessing the actual benefits of UR management. It is possible to perform a nationwide evaluation of water quality impacts because the information is site-specific. Instead, comparisons can be made between dry-weather plant and combined sewer overflow loadings from similar areas to indicate the relative magnitude from this source. Table 2 summarizes the contribution of various pollutants from different sources on a nationwide basis. The dry-weather flow was calculated based on an average population density of 102.7 people/ha (41.6 people/acre) (4) and a flow equivalent of 473 ℓ/person/day (125 gal/person/day). A secondary effluent of 30 mg/l suspended solids and BOD$_5$, and 1 mg/l phosphorous were assumed. For the untreated CSO contribution, average reported concentration values for this flow were utilized (1). An average rainfall of 0.91 m (36 in) with 50 percent runoff was assumed. The basis for UR loadings is presented in detail in Section 5.

TABLE 2. NATIONAL POLLUTANT LOADINGS ASSOCIATED WITH DIFFERENT POLLUTION SOURCES

	Annual loadings, lbs/acre/year		
	Dry weather flow (secondary effluent)	Combined sewer overflow	Urban runoff
Suspended solids	474	1,508	1,490
BOD$_5$	474	469	71.8
Nitrogen	-	15.5	5.06
Phosphorus	15.8	8.0	2.23

Metric conversion:
lb/acre/year x 1.121 = kg/ha/year

The most significant contribution of UR is associated with suspended solids. The BOD$_5$ loadings are one-fifth of those associated with either the dry-weather plant or CSO. Nutrient loadings are also significantly less. The suspended solids loadings are summarized in Figure 1. It can be seen that

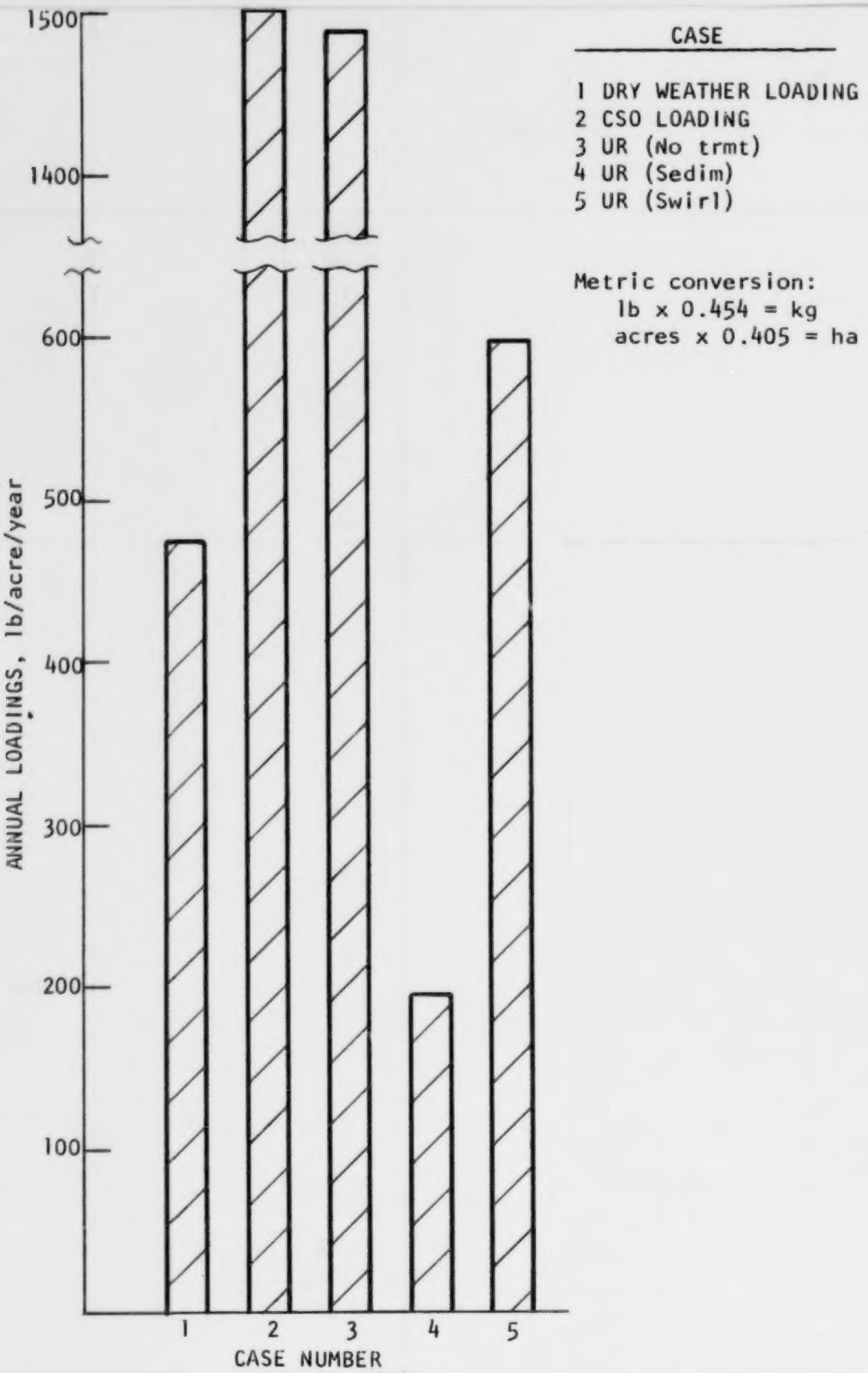

Figure 1. Annual suspended solids loading - national basis.

for this parameter, the loadings associated with UR are approximately the same as those from CSO and are three times greater than the dry-weather contributions. Implementation of most management techniques greatly decreases the suspended solids loadings from UR because of the generally high removal efficiencies for this parameter.

A more complete evaluation can be made for the Milwaukee River Basin Area. The average pollutant quality of the river upstream of the urban drainage area has been quantified through a comprehensive sampling and monitoring program and then compared to the pollutant loadings generated by UR during the same year (See Table 3).

TABLE 3. COMPARISON OF POLLUTANT LOADING IN THE MILWAUKEE RIVER BASIN

	Annual loadings, million lb/year		
	Upstream river contribution	Urban runoff (no treatment)	Urban runoff (sed. treatment)
Suspended solids	9.84	8.19	1.09
BOD_5	11.97	2.19	1.09
Nitrogen	0.97	0.096	0.014
Phosphorus	0.088	0.047	0.029

Metric conversion:
lb x 0.454 = kg

It can be seen that the UR loadings associated with this drainage area can double the suspended solids and BOD in the river. Nutrients are less impacted, although phosphorus is increased by about 50%. Another approach is to consider the contributions by other discharges. Table 4 compares annual loadings per unit area of combined sewer overflow, dry-weather plant discharges and UR. For this evaluation, it has been assumed that the 10,772 ha (26,597 acre) drainage basin is populated by 173,000 people and that the treated dry-weather effluent (29 mg/l SS, 17 mg/l BOD_5, and 0.51 mg/l phosphorus) is directed to the river. The CSO loads are a result of previous modeling studies for the Milwaukee CSO Project (9).

It can be seen that the combined sewer overflow discharges contribute a much greater amount of pollutants per unit area to the river. However, less area is served by combined sewers [2,268 ha (5,600 acres)]. The UR generates significant amounts of suspended solids and BOD_5 with lower nutrient amounts.

TABLE 4. COMPARISON OF POLLUTANT LOADINGS FROM OTHER SOURCES - MILWAUKEE RIVER BASIN

	Annual loadings, lb/acre/year		
	Dry-weather plant	CSO	Urban runoff
Suspended solids	71.6	1,106	319
BOD_5	42.0	438	82.3
Nitrogen	-	33.6	3.6
Phosphorus	1.2	13.2	1.8

Metric conversion:
lb/acre/year x 1.121 = kg/ha/year

Figure 2 gives a comparison of loadings for suspended solids to show how various treatment management practices impact the loadings to the receiving water. It can be seen that all systems will reduce loadings. However, swirl concentration treatment still significantly exceeds normal dry-weather plant loadings. To establish which management procedure is best, it is necessary to evaluate other impacts as well as water quality.

Cost Impacts

The main emphasis in this report has been on the development of costs associated with disposal of either sludges generated by UR treatment or residues from streetsweeping. The various calculated costs are summarized in Table 5 on a national basis and for the Milwaukee River Basin. Figure 3 presents a comparison of the cost ranges for the different UR areas evaluated. The lower disposal costs for streetsweeping residues are apparent from this presentation.

For comparison purposes, generalized annual costs for both streetsweeping and UR treatment have been developed. Swirl concentration annual costs and sedimentation operating costs are based on general equations presented in Table 11 of Reference 4. Storage basin costs were estimated based on data included in Reference 9. Streetsweeping costs were developed from Reference 55. All costs have been updated to reflect June, 1977 values. The treatment costs and annual costs including disposal are summarized per area in Table 6.

It can be seen that the disposal costs can increase the annual costs by 6 to 80 percent depending on the management techniques. Because of the high costs of sedimentation treatment, sludge disposal costs add proportionally less to the costs although the unit costs are equal to or higher than other methods. Swirl concentration sludge disposal can add significantly (40 to 70 percent) to the annual costs. These values indicate the importance of including sludge or residual handling and disposal costs in the total evaluation of any system.

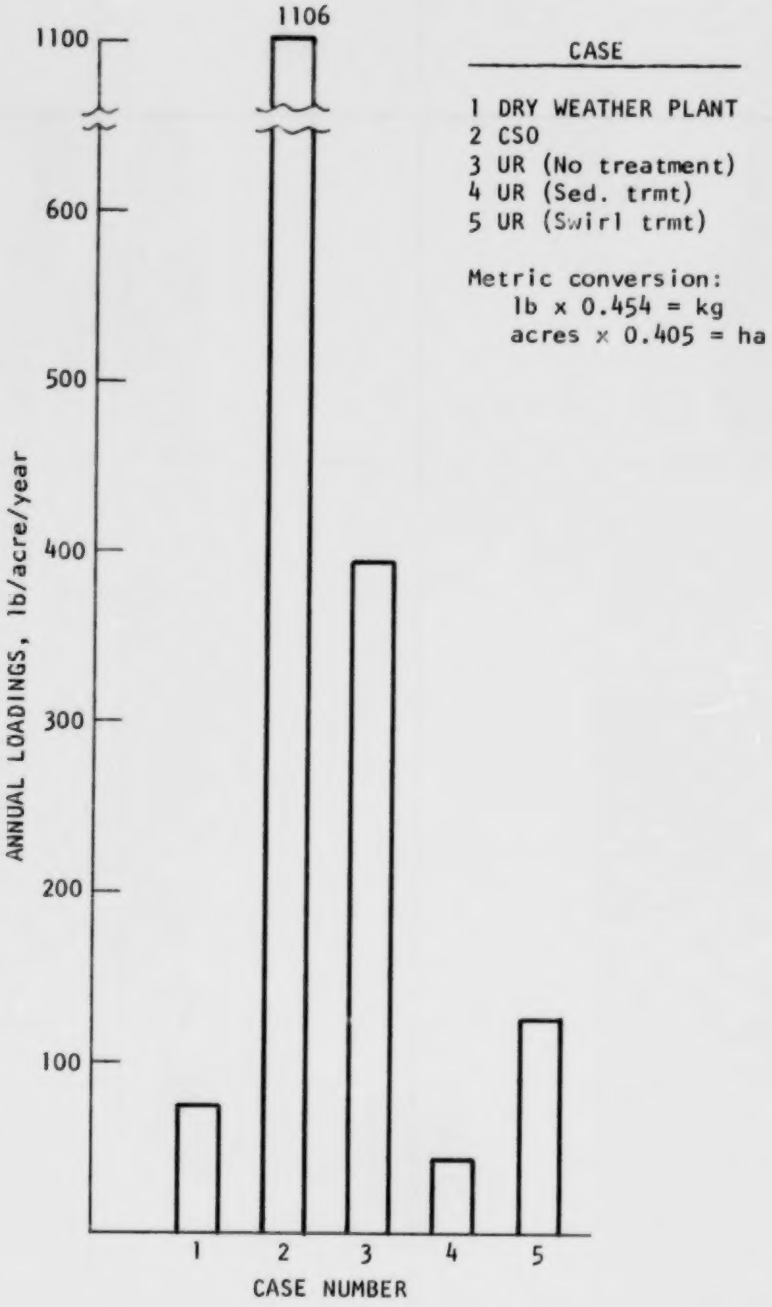

Figure 2. Suspended solids loadings - Milwaukee River Basin area.

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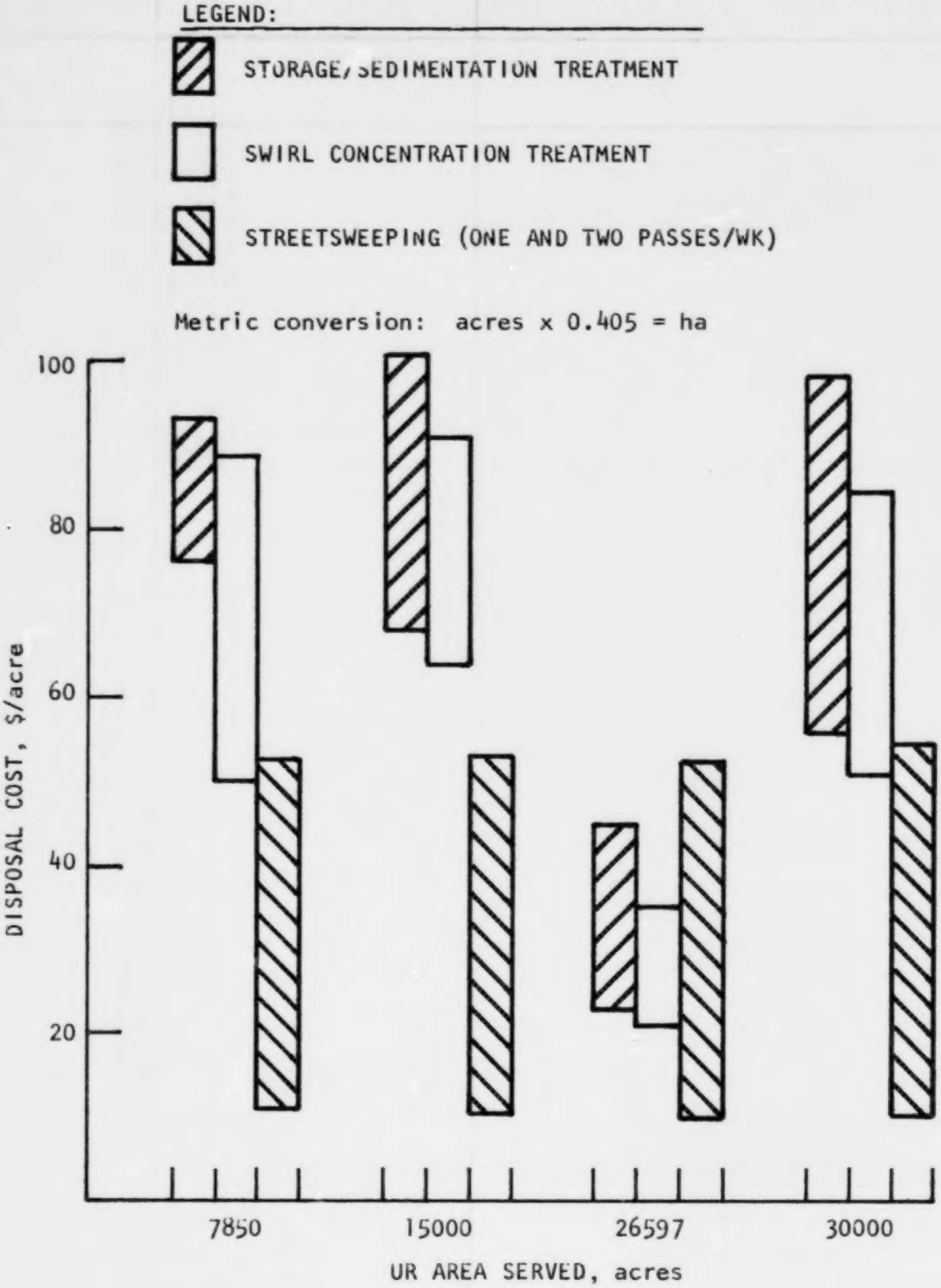

Figure 3. Cost ranges for disposal options.

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TABLE 5. DISPOSAL COSTS FOR URBAN RUNOFF MANAGEMENT OPTIONS

	Cost, $/acre	
	National	Milwaukee
Treatment Alternatives*		
Storage/sedimentation		
#1	71.46 - 82.23	27.61
2	93.74 - 98.05	29.76
3	56.12 - 77.32	23.57
4	72.95 - 88.29	24.88
5	-	32.18
6	78.98 - 96.83	45.60
Swirl Concentration		
1	61.68 - 76.19	24.48
2	76.89 - 89.58	26.31
3	56.43 - 64.10	21.21
4	64.19 - 78.37	22.56
5	79.59 - 91.33	35.51
6	438 - 657	368.24
Streetsweeping (One and two passes/week)	9.71 - 53.24	-

*Alternatives 1-6 are defined in Section 7.
Metric conversion:
acres x 0.405 = ha

TABLE 6. TREATMENT AND ANNUAL COSTS FOR URBAN RUNOFF MANAGEMENT TECHNIQUES

Drainage Area, acres	Swirl treatment	Sedimentation treatment	Streetsweeping
	Treatment cost, $/acre		
7,850	131	920	8-40
15,000	107	909	8-40
30,000	88	896	8-40
26,597*	84	648	8-40
	Annual costs, $/acre		
7,850	181-222	997-1,014	10-53
15,000	171-198	977-1,011	10-53

-continued-

Table 6. continued

Drainage Area, acres	Swirl treatment	Sedimentation treatment	Streetsweeping
30,000	139-173	952-994	10-53
26,597*	105-120	672-694	10-53

* Milwaukee River Basin
Metric conversion: acres x 0.405 = ha

Land Area Requirements

The third primary impact which can be compared is the land area requirement. This involves both urban land areas for storage systems and outlying disposal site needs. The range of area requirements for the various techniques are summarized in Tables 7 and 8. It has been assumed that the sedimentation sludge handling equipment is located above the storage basin and that streetsweeping requires no additional land area than already required by the city Department of Public Works. The areas required for storage/sedimentation are very high compared to use of the in-line swirl control device.

Table 8 summarizes the landfill area requirements calculated using the assumptions presented in Section 7. The area needs are dependent upon the specific gravity of the residues and the total weight of material being disposed. Sedimentation generates the greatest amount of sludges for disposal. The higher specific gravity of the streetsweepings results in a much lower area requirement for this material. The lower landfill area needs for Milwaukee reflect the lower UR suspended solids concentrations and again emphasize the need for an in-depth evaluation on a site-specific basis.

Landspreading requires much greater land areas,which may or may not be publically owned. For the national evaluation, the area required was directly related to the solids and metals removals, so swirl concentrator sludge requires less landspreading area. For Milwaukee, the loadings varied, so sedimentation sludge,with its higher metal concentrations,required more area.

These land requirements can be compared to the needs for a dry-weather plant serving the same area. If it is assumed that these sludges are landfilled at 20 percent solids, the annual landfill needs are summarized as follows:

	UR Area		Landfill Area Required
	3,179 ha (7,850 acres)	-	66.4 ha (164 acres)
	6,075 ha (15,000 acres)	-	127 ha (313 acres)
	12,175 ha (30,000 acres)	-	253 ha (626 acres)
Milwaukee	10,772 ha (26,597 acres)	-	225 ha (556 acres)

The additional solids associated with UR management techniques add approximately 15 to 20 percent extra space requirements to a landfill area for UR

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TABLE 7. URBAN AREA REQUIREMENTS FOR STORAGE AND TREATMENT ALTERNATIVES

Drainage Area (acres)	Area needed, acres	
	Storage/sedimentation	Swirl
7,850	13.9-44.0	0.32-0.38
15,000	26.6-84.3	0.63-0.71
30,000	53.1-168.4	1.28-1.42
26,597*	58.9-116.3	0.58-1.20

Metric conversion: acres x 0.405 = ha
*Milwaukee

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TABLE 8. DISPOSAL AREA REQUIREMENTS

Drainage Area, (acres)	Sedimentation	Swirl	Housekeeping
	Land spreading area, acres		
7,850	694	484	-
15,000	1,321	937	-
30,000	2,121	1,877	-
26,597*	187	247	-
	Landfill area, acres		
7,850	19-27	13-19	25-32
15,000	36-52	26-37	49-61
30,000	73-104	52-73	98-121
26,597	15-25	11-17	78-96

*Milwaukee

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treatment sludges but add appreciably less for streetsweeping residuals. The ultimate impact of area needs will be dependent upon landfill availability and the new regulations regarding solid waste disposal.

SECONDARY IMPACTS

It is not possible to accurately quantify the secondary impacts associated with UR management techniques on a general basis. As a result, direct comparison of the impacts caused by sludge handling or streetsweeping is difficult. Instead, a generalized approach has been taken which identifies the potential secondary impacts and contrasts their overall effect.

The secondary impacts involved include water pollution, air pollution, noise, energy consumption, vectors, odors, soil impacts and plant uptake. These impacts are associated with various aspects of the UR management techniques investigated namely (a) contaminant removal (UR treatment and sweeping operations) and (b) ultimate disposal (landspreading and landfill).

Secondary Impacts Associated with Contaminant Removal

Contaminant removal secondary impacts include energy consumption, noise and air pollution. These impacts are associated with the use of vehicles in the streetsweeping operations and in the transporting of UR treatment sludges and sweepings to disposal sites.

The actual impact is a direct function of the frequency of UR treatment and streetsweeping and of the nature and volume of sludges and sweepings generated for disposal. Comparing UR treatment and streetsweeping, it may be noted that vehicles are not utilized during UR treatment but are essential and intensively used in streetsweeping operations. On the other hand, in transporting the sludges and sweepings to a disposal site, the transportation impacts for treatment sludges may be more intensive than those for streetsweeping because greater volumes and more trips are necessary for sludges. For example, streetsweepings are transported dry and are more dense (specific gravity - 2.5) than sludges which contain 60 to 95 percent water and have a specific gravity of 1.05 to 1.25. A comparison of the annual volumes of residues generated per unit area (ha or acres) on a national basis may illustrate this. For swirl concentration treatment, there were 2.36 to 3.31 m^3/ha/year (1.25 to 1.75 yd^3/acre/year) generated compared to 3.32 to 4.76 m^3/ha/year (1.76 to 2.52 yd^3/acre/year) for sedimentation treatment and 0.036 to 0.236 m^3/ha/year (0.019 to 0.125 yd^3/acre/year) for streetsweeping (one cleaning pass per week).

Air pollution impacts include increased emissions as well as dirt and dust generation associated with the greater number of vehicle miles driven in transporting sludges to disposal sites. On the other hand, lesser emissions and dirt and dust generation may be expected from streetsweeping operations. In fact, it is indicated (55) that streetsweeping may play an important role in controlling street surface particulate losses to the air caused by wind and vehicle travel.

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Secondary Impacts Associated with Ultimate Disposal

Disposal secondary impacts include water pollution effects, vectors, air and noise pollution, odors, effects on sensitive and unique areas, soil impacts and plant uptake. All of these must be considered for a site-specific evaluation but most can be minimized by proper design and operation of a disposal site.

Water pollution impacts may be the most significant of those associated with disposal. Both surface and ground-water contamination may result from improper operation of disposal sites. The leachate qualities associated with landfill of either UR sludge or streetsweeping has not been defined, however, both could cause nutrient or metal contamination of the ground water. Table 9 shows the characteristics of streetsweepings compared to UR sludges. The leachate quality will be related to these differences. It is anticipated that the sludge will result in a more contaminated leachate with regard to BOD, nitrogen, phosphorus and most metals. Lead and copper concentrations are exceptions since the sweepings contain larger amounts of these constituents. Runoff quality would be affected in the same manner. However, proper site management should eliminate substantial runoff problems.

Vectors including rodents and insects may be more substantial around street sweepings since these materials may not be stabilized prior to disposal. The same may be true for odor problems.

Noise pollution is associated with vehicle use for the two UR management techniques investigated. Vehicle use is more intensive during contaminant removal for streetsweeping operations than it is during UR treatment. Conversely, vehicle use is greater for transporting sludge to a disposal site than for transporting sweepings because of the appreciably greater volume of sludge than sweepings generated for disposal.

Regarding air pollution, vehicle use during sludge transportation contributes to air pollution by resuspending dirt and dust into the atmosphere. On the other hand, it is indicated that streetsweeping beneficially reduces air pollution by removing dust and dirt that might otherwise be resuspended into the atmosphere by wind and vehicular travel.

When considering landspreading, the additional problems of soil conditions and plant uptake must be evaluated. Since landspreading is only associated with the sludges, they have been shown to be metal limiting. As a result, if proper loadings are utilized, uptake problems should not occur. Finally, the beneficial effects of UR sludge as a soil conditioner are minimal so landspreading should be considered only as a disposal option.

TABLE 9. COMPARISON OF QUALITY OF DUST AND DIRT TO UR SLUDGES

Pollutant*	Dust and dirt quality by land use (1)				UR Sludge quality
	Single family residential	Multifamily residential	Commercial	Industrial	
BOD_5	5,260	3,370	7,190	2,920	27,800-40,300
COD	39,300	42,000	61,700	25,100	-
Total nitrogen	460	550	420	430	1,140-3,370
Soluble PO_4-P	16	19	20	8	502-1,270
Cadmium	3.3	2.7	2.9	3.6	21
Chromium	200	180	140	240	-
Copper	91	73	95	87	252-294
Iron	21,300	18,500	21,600	22,500	118-10,067
Manganese	450	340	380	430	-
Nickel	38	18	94	44	69-143
Lead	1,570	1,980	2,330	1,590	251-294
Strontium	32	19	17	13	-
Zinc	310	280	690	280	302-352
Fecal coliforms, No./g	82,500	388,000	36,900	30,700	-
Total coliforms, No./g	891,000	1,900,000	1,000,000	419,000	-

*mg/l of dry solids unless otherwise indicated.

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SECTION 5

URBAN RUNOFF SLUDGES - A DEFINITION OF THE PROBLEM

GENERAL

Prior to any evaluation of primary or secondary impacts associated with handling UR sludges, it is necessary to quantify the extent of the problems. Since no literature was available which presented the qualities of sludges generated by UR treatment processes, and sampling/characterization was not part of this study, the sludge volumes and quantities had to be estimated. This involved definition of the quality of UR from published or water quality model data, followed by calculation of sludge quantities and qualities based on published percent removals and similarities to CSO sludges. Several different UR treatment processes were considered. The characterization was performed on a generalized national basis and for a drainage basin in the City of Milwaukee to illustrate differences between national estimates and specific runoff qualities predicted by a calibrated water quality model.

CHARACTERISTICS AND VOLUMES OF URBAN RUNOFF

Separate stormwater runoff is discharged from storm drainage systems and contains contaminants from street, land and building surfaces and air fallout. Of the total U.S. sewered population of 115,459,000, 67 percent or 77,853,000 people are served by separate storm sewers (4). This large area can contribute a tremendous volume and weight of pollutants to the nation's waterways.

National Urban Runoff Characteristics

National Volume of Urban Runoff--
Because the nature of UR is extremely variable both in volume and quality, it is not possible to accurately predict a generalized national UR volume. For this review, instead, an average estimate has been prepared which will illustrate the basic magnitude of the problem. To accomplish this, several assumptions were required:

1. Average Annual Precipitation of 0.91 m (36 in.)(Ref 5). Range is 0.13 to 2.54 m (5 to 100 in.) (See Figure 4).
2. Amount of precipitation which runs off - 44 percent (Ref 4).
3. Sewered area - 725,000 ha (1.79×10^6 acres) (Ref 4).

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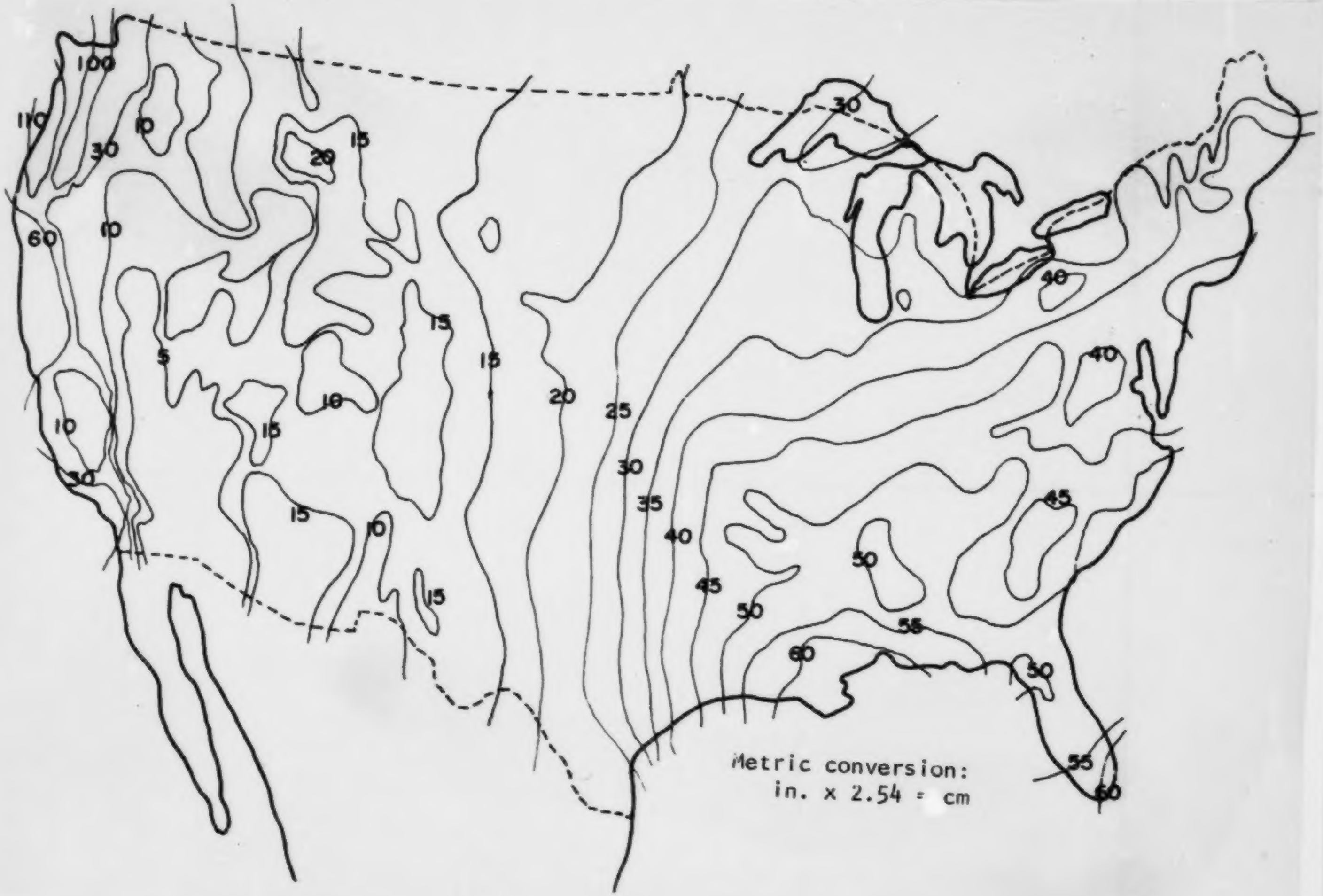
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Metric conversion:
in. x 2.54 = cm

Figure 4. United States median annual precipitation (5).

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From this information, the average volume of UR on a national basis was calculated to be 2.9×10^9 m^3/year (7.7×10^5 M gal/year).

National Urban Runoff Quality--

Establishing average characteristics for UR is also difficult due to the many factors which influence the quality of this discharge. Among the critical variables which impact the UR characteristics are the duration and intensity of rainfall, time between storm events, surface area drained, street cleaning procedures, land use patterns and topography. Complete discussions of UR quality have been presented elsewhere (1,2) and the variation in characteristics is apparent. However, for the purpose of establishing basic pollutant amounts, it is possible to utilize average values as presented in the literature (1). These values and their ranges are presented in Table 10. Again the reader must understand that the data is an average of much information and does not indicate quality at a specific site. The concentrations of metals other than lead have been reported in various literature sources (2,6,7). The national averages are presented in Table 11.

Milwaukee River Basin Urban Runoff Characteristics

To illustrate the differences between UR volumes estimated on a national basis, and volumes predicted through water quality models, the evaluation of urban runoff sludges was expanded to include characterization of a specific storm sewered area. The City of Milwaukee was chosen since detailed water quality data was readily available to the project personnel.

Description of the Area--

The Milwaukee area has a total of 34,830 hectares (ha) (86,000 acres) served by storm sewers, within its metropolitan boundaries and 5,670 ha (14,000 acres) with combined sewers, which contribute to three rivers in the area (Figure 5). In order to evaluate the UR quality from a typical storm sewered area, the Milwaukee River Basin storm sewered area of 10,772 ha (26,597 acres) was chosen for the following reasons:

1. It contains the highest percentage of residential land use within the metropolitan storm sewered area.
2. It has the most monitoring data available on storm runoff quantity and quality.
3. It represents a basin area which is larger than approximately 80 percent of the storm sewered areas on a nationwide basis (4).

Runoff Quantity and Quality--

In order to determine an average quality of the stormwater discharges in the Milwaukee area, the Corps of Engineers STORM model was utilized. The model was applied and calibrated as part of a previous project to evaluate water quality impacts from stormwater on the Milwaukee River (8). Average stormwater quality was determined by running STORM for a typical runoff year.

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(4-76)

TABLE 10. POLLUTANT CONCENTRATIONS IN STORMWATER RUNOFF (1)

City	Average pollutant concentrations, mg/l									
	TSS	VSS	BOD_5	COD	Kjeldahl nitrogen	Total nitrogen	Phos-phorus	PO_4-P	Lead	Fecal coliforms*
Atlanta, Georgia	287	-	9	48	0.57	0.82	0.33	-	0.15	6,300
Des Moines, Iowa	419	104	56	-	2.09	3.19	0.56	0.15	-	-
Durham, North Carolina	1,223	122	-	170	0.96	-	0.82	-	0.46	230
Knoxville, Tennessee	440	-	7	98	1.9	2.5	0.63	0.30	0.17	20,300
Oklahoma City, Oklahoma	147	-	22	116	2.08	3.22	1.00	1.00	0.24	40,000
Tulsa, Oklahoma	367	-	12	86	0.85	-	-	0.38	-	420
Santa Clara, California	284	70	20	147	-	5.8	0.23	-	0.75	-
Pullach, Germany	158	53	11	125	-	-	-	-	-	-
Average (not weighted)	415	88	20	113	1.41	3.11	0.62	0.46	0.35	13,500
Range	147-1,223	53-122	7-56	48-170	0.57-2.09	0.82-5.8	0.33-1.00	0.15-1.00	0.15-0.75	230-40,000

* Organisms/100 ml.

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The typical runoff year was selected from 38 years of runoff predictions with STORM, using the following selection criteria:

1. Number of runoff events
2. Total volume of runoff
3. Average runoff per event
4. Distribution of runoff events during the year

Each runoff year was ranked for the first three criteria. Several typical years were selected by comparing the values for these criteria with the mean and median values for the 38 year period. The distribution of events was used to select 1955 as the typical runoff year. The total rainfall in 1955 was 27.40 inches (69.60 cm) which is slightly less than the annual average precipitation of 29.05 inches (73.79 cm). The prediction concentrations for this storm sewer area are the result of approximately 60 individual runoff events occurring during the typical runoff year. The rainfall record was in-put to the STORM model on an hourly basis for the entire 12 months of record. The UR quality predicted by the model is presented in Table 12. These concentrations appear low when compared to the national averages included in Table 10, however, it must be remembered that these values represent concentrations of UR constituents averaged over the entire duration of the storm. The model predicts the true composite concentrations from an entire series of storms, with some lasting as long as 16 hours. Therefore, the tail end of the storm runoff, with a more dilute flow which is not normally contained in most composite samples, is included in the predictions. Another factor which contributes to the lower suspended solids concentrations in the runoff from Milwaukee is the relatively large area containing low density residential

TABLE 11. AVERAGE METAL CONCENTRATIONS FOR URBAN RUNOFF

Metal	Average concentration, mg/l	Range	Reference
Zinc	0.36	0.09-4.60	2,6,7
Aluminum	16	6-36	6
Calcium	4.8	1.1-31.0	6
Cobalt	0.19	0.04-0.47	2,6
Chromium	0.20	0.06-0.47	6,7
Copper	0.30	0.04-0.50	2,6,7
Iron	12	1.3-58.7	6
Lead	0.30	0.10-2.86	2
Magnesium	10	4-24	6
Manganese	0.67	0.12-3.20	2,6
Nickel	0.15	0.09-0.29	2,6,7
Cadmium	0.025		7

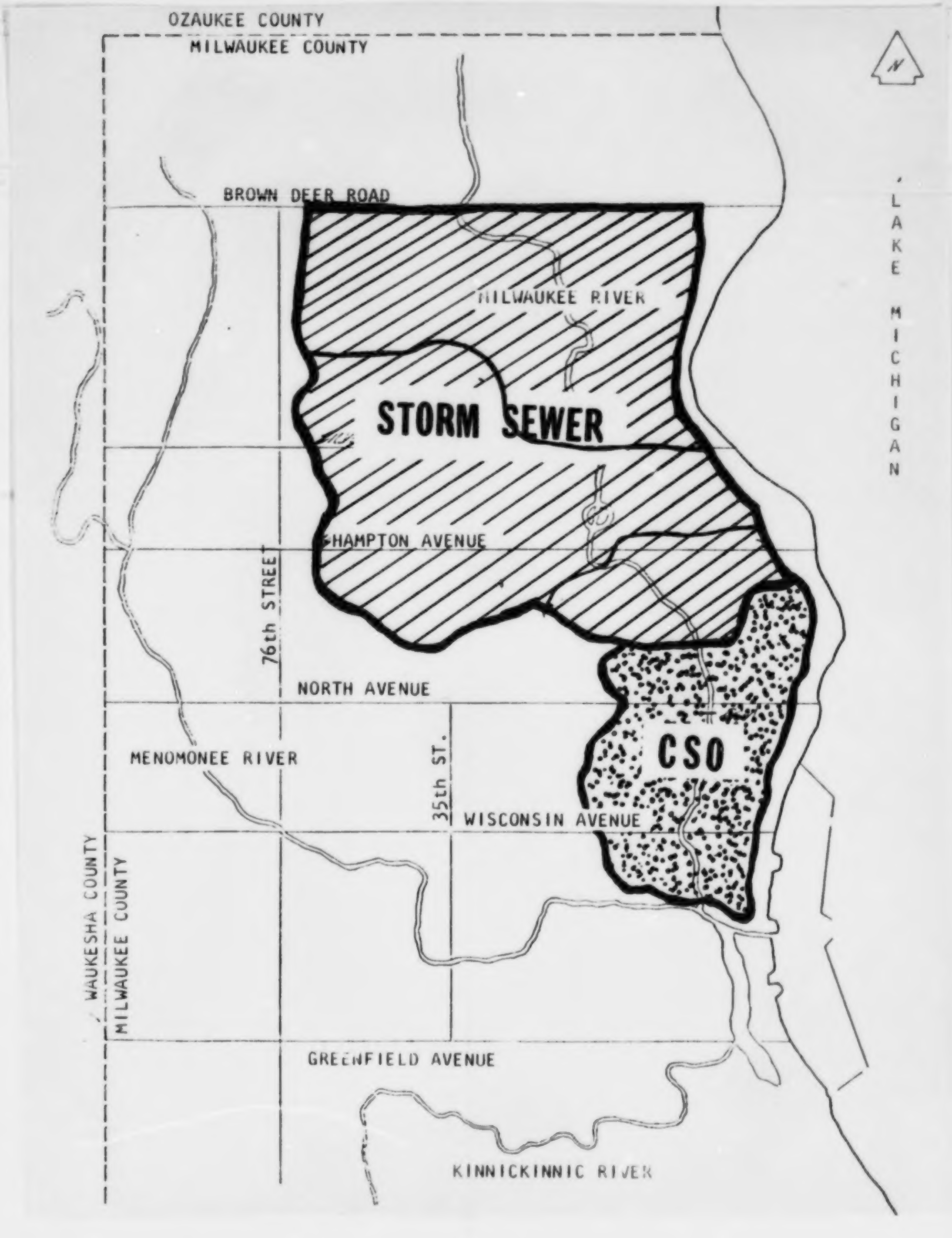
OZAUKEE COUNTY
MILWAUKEE COUNTY
N
BROWN DEER ROAD
MILWAUKEE RIVER
STORM SEWER
LAKE MICHIGAN
HAMPTON AVENUE
76th STREET
NORTH AVENUE
CSO
MENOMONEE RIVER
35th ST.
WISCONSIN AVENUE
WAUKESHA COUNTY
MILWAUKEE COUNTY
GREENFIELD AVENUE
KINNICKINNIC RIVER

Figure 5. Milwaukee River Basin drainage areas.

TABLE 12. MILWAUKEE RIVER BASIN URBAN RUNOFF QUALITY

Parameter	Units	Concentration
Suspended solids	mg/l	156
Settleable solids	ml/l	13.2
BOD_5	mg/l	40
Total nitrogen	mg/l	1.8
Total phosphorus	mg/l	0.87

neighborhoods. These are prevalent in Milwaukee as distances from the central city increase. Larger lots with grassy ditch conveyance of the runoff to storm sewers that discharge to the river are common in this area. The natural attenuation properties of this type of land use reduce associated pollutant loadings.

Metals concentrations were not predicted by the model. Instead, these values were based on averages of composite samples collected during different storm events. The metals concentrations were assumed to be:

Cadmium - mg/l - 0.02 (0.02 soluble)
Lead - mg/l - 0.11 (<0.10 soluble)
Copper - mg/l - 0.05 (0.04 soluble)
Zinc - mg/l - 0.20 (0.09 soluble)
Iron - mg/l - 0.95 (0.09 soluble)

General Impact

When assessing the general impact of UR on the environment, the total magnitude of the problem is difficult to comprehend. On an average national basis, there are 1.2×10^9 kg (2.6×10^9 lb) of suspended solids and 5.86×10^7 kg (1.29×10^8 lb) of BOD discharged per year as a result of UR. This compares to a total of 1.23×10^9 kg (2.7×10^9 lb) of suspended solids and BOD generated per year from domestic sewage for the total sewered population of the United States [based on 200 mg/l suspended solids and BOD_5 influent, a flow of 473 ℓ/person (125 gal/person) and a sewered population of 36,236,000 (4)]. Assuming secondary treatment and removals to effluent limits of 30 mg/l BOD_5 and suspended solids, the annual loadings to receiving waters are calculated to be 1.84×10^8 kg (4.05×10^8 lb) of suspended solids and of BOD_5. Comparison of the values indicates the untreated UR solids loadings are greater than those expected from treated domestic sewage. The potential benefits associated with reducing impacts of UR could be substantial. These calculations do not consider instances of extremely heavy, localized UR loadings on the waterways caused by the unknown frequency of rainfall events. Comparing these values indicates the potential benefits associated with reducing the impact of UR by various treatment or management practices.

CONTROL METHODS

The different techniques which can be utilized to reduce or eliminate pollution associated with UR have been reviewed and described in detail in the literature (1,2). Therefore, it is not necessary or desirable to include a detailed discussion in this report. Instead, the highlights will be presented as a brief overview of potential control techniques.

Best Management Practices

One approach to handling the UR pollution problems involves implementation of non-structural or low structurally intensive alternatives, called best management practices (BMP's). Some procedures are more effective when implemented prior to the development of a specific urban area, since problem prevention can be used to contain all or most of the runoff and pollutants. Among these techniques are land use planning, and operation and maintenance practices. Land use planning can invlove the use of natural land areas for containment or detention, avoidance of construction in certain areas, and erosion control. Its main usefulness is for undeveloped or developing areas. Corrective maintenance and operation procedures include litter control, chemical use control, streetsweeping, street maintenance and sewer and catchbasin maintenance. It is felt that program success requires the implementation of various laws and ordinances which will force compliance, however, the exact benefits of these procedures are not well defined (1).

Treatment Options

Another method of handling UR involves using storage and/or physical treatment methods to reduce pollutant loadings. These options can be implemented either instead of, or in addition to BMP's, depending on their cost-effectiveness at a given location. The benefits associated with treatment are apparent, however, in order to properly assess the total impact, some of the secondary environmental effects including disposal effects, nuisance problems and odor should also be considered.

Choice of Methods

Prior to implementation of any control technique, it is important to evaluate the overall impact on the site-specific situation. The information presented in this report presents the types of primary and secondary impacts associated with UR sludge or residual handling which should be considered when performing an evaluation. In addition, relative impacts can be assessed by this study. However, final evaluation and system choice must be considered on an individual site-specific basis.

IMPLEMENTATION OF TREATMENT OPTIONS

If it is determined that treatment appears to be necessary for a given site, then the primary and secondary impacts can be evaluated. Some of the most apparent effects are associated with the sludge or residual handling. These can include not only design and operation of control facilities and disposal sites but also secondary problems such as leachate production, landfill needs, increased air pollution from transportation, etc. Prior to consideration of these impacts, it is first necessary to define sludge characteristics and volumes associated with residuals from various UR treatment processes.

Storage/Retention Basins

Due to the extremely variable nature of UR flows, some type of storage or retention is often required for effective treatment of the runoff. Various types of storage can be utilized including central or localized storage areas, collection system utilization, or surface attenuation. Central storage can be either above or below the ground surface depending upon land area availability and the subsoil structure. It involves collection of the runoff from an upstream drainage area into one large chamber (3). Localized storage can be utilized for smaller drainage areas within a total storm sewered section. These are multiple units which can be either above or below ground. This type of storage system can be used prior to further treatment or as equalization/retention systems to reduce peak flows.

In some instances, the collection system itself can be utilized to provide additional storage. This procedure involves the use of various gates and controls to contain the flow in-line, and control the rate of discharge. Another technique may be retention using land surface attenuation techniques. Large surfaces such as roof tops, parking structures, mall areas, streets, etc. may be modified to retain a certain volume of runoff. These procedures have the advantage of requiring little construction but they are difficult to implement in certain areas and can be the source of potential freezing, safety and nuisance problems which are unacceptable to the public.

Land Area Availability

When evaluating handling options for UR, one of the most serious considerations involves land area availability. Since most UR treatment techniques require inclusion of some type of preliminary storage to increase operating efficiency, land must be available for placement of a storage/retention basin, otherwise the option might not be viable.

In order to highlight the potential impact of storage on land area availability, the land requirements for storage retention of different type storms and area sizes have been calculated. First, representative UR areas were identified by evaluating the size distribution of urban areas served by storm sewers (4). The area size distribution for these 229 urbanized areas is presented in Table 13.

Three sizes were chosen to represent a cross-section of areas and then UR storage area requirements were calculated. The drainage area sizes chosen were: 1) 3,180 ha (7,850 acres) which corresponds to a typical sized urbanized area, 2) 6,075 ha (15,000 acres) which represents a mid-sized area and 3) 12,150 ha (30,000 acres) which represents a large size area. More than

TABLE 13. DISTRIBUTION OF URBAN STORM SEWERED AREAS (4)

Average area - 3,180 ha (7,850 acres)

Number of urbanized areas in size range	Area	
	ha	Acres
114	<3,180	< 7,850
51	3,180 - 6,075	7,850 - 15,000
31	6,075 - 12,150	15,000 - 30,000
33	>12,150	>30,000
Total 229		

85 percent of the number of urbanized areas are represented by this range. The Milwaukee River storm sewered area of 10,772 ha (26,597 acres) was also utilized in the calculation to allow comparison between an actual location and more generalized estimates.

Four types of rain events were used in the evaluations. Both five year and one year design storms were used to illustrate the impact that different storm frequencies have on storage needs. One and twenty-four hour storm durations we also utilized to indicate the effect of this variable. The runoff amounts were calculated based on rainfall data provided in the U.S. Weather Bureau Technical Publication No. 40. (56). Average rainfalls and a runoff percentage were then used to calculate the volumes required. Actual rainfall data available for the City of Milwaukee were used for this estimate. The required storage volumes for the one hour storms were set to be equal to the runoff volume since the pump-out rates have little effect on the required volumes to contain 100 percent of the runoff. The 24-hour duration storms are affected by the pump-out rates and the storage volumes are reduced to reflect these rates. The runoff from the 24-hour duration storms was assumed to occur in 6-hour intervals with half the overflow arriving in the first 6-hour time period in order to provide a more reasonable runoff hydrograph and storage utilization curve. The required storage volumes are presented in Table 14. It can be seen that different design storms have a significant impact on storage requirements. A storm less frequent than once per year will result in even lower storage volume requirements. The choice of design storm is dependent upon individual considerations in the specific area, but the impact of this choice should not be overlooked.

The associated area requirements are dependent upon the type of basin utilized and its depth. In some locations, underground or in-line storage is possible which will reduce area needs. When ground level storage is considered, either lined earthen or concrete basins could be utilized. Earthen basin storage is most feasible in undeveloped areas, whereas concrete basins may be more appropriate in central city industrial areas (9). The basin depth is a critical variable which defines actual area requirements. The relationship between depth and area requirements is illustrated in Figure 6. For example, if a 4.6 m (15 ft) depth is assumed, the area requirements for the different storage volumes can be calculated. The results are presented in Table 15.

All area requirements must then be considered from the standpoint of centralized or multiple storage. If a single location is required, routing the flows to a single point, as well as finding the large areas required, would be extremely difficult. However, if numerous multiple units were to be utilized, then parklands or other undeveloped small sized areas may be available. It may even be possible to "reclaim" the area if covered underground storage is utilized.

The land areas required for centralized storage are therefore quite significant, especially when the availability of urban land is considered. There is no nationwide evaluation of vacant land in populated urban areas, however,

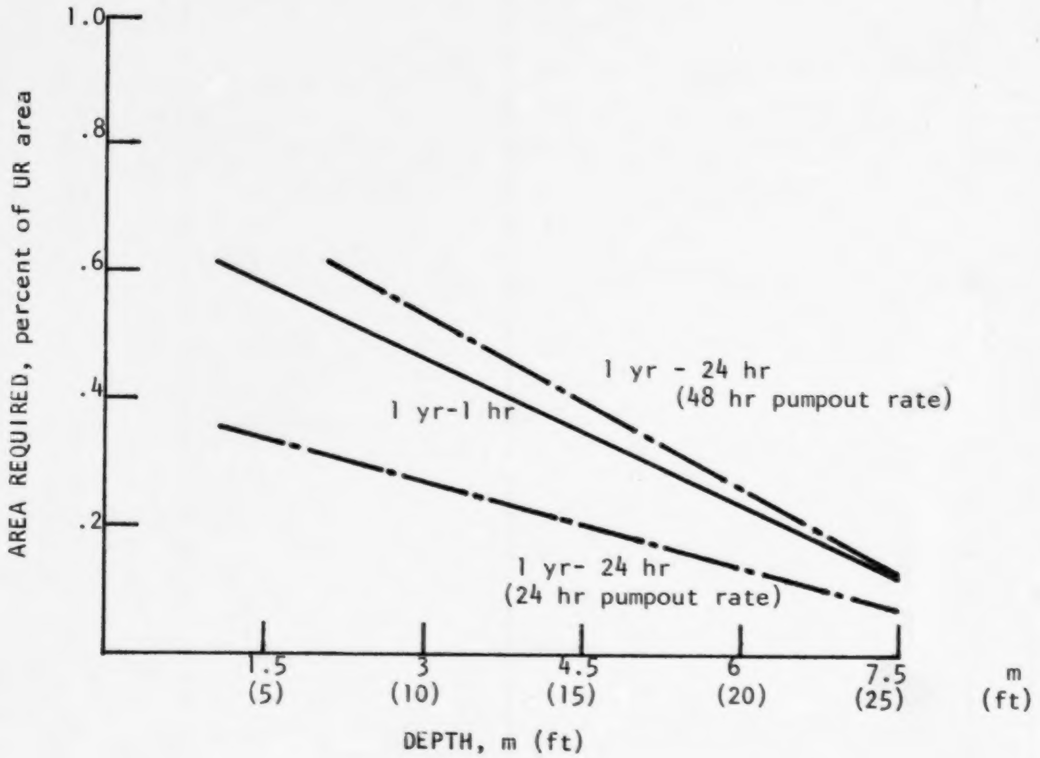

Figure 6. Area requirements as a function of depth.

TABLE 14. CALCULATED STORAGE VOLUMES FOR VARIOUS DESIGN STORMS

		1 year storm		5 year storm	
Storm duration	UR area, acres	Storage volume, ft^3	Pump-out rate, ft^3/sec.	Storage volume, ft^3	Pump-out rate, ft^3/sec.
1 hour	7,850	1.63×10^7	189 (24 hr)	2.51×10^7	290 (24 hr)
			94 (48 hr)		145 (48 hr)
	15,000	3.11×10^7	360 (24 hr)	4.79×10^7	555 (24 hr)
			180 (48 hr)		277 (48 hr)
	30,000	6.23×10^7	721 (24 hr)	9.58×10^7	1,109 (24 hr)
			360 (48 hr)		555 (48 hr)
	26,597*	5.36×10^7	621 (24 hr)	7.60×10^7	880 (24 hr)
			310 (48 hr)		440 (48 hr)
24 hours	7,850	9.09×10^6	421 (24 hr)	1.44×10^7	668 (24 hr)
		1.82×10^7	210 (48 hr)	2.88×10^7	334 (48 hr)
	15,000	1.74×10^7	804 (24 hr)	2.76×10^7	1,276 (24 hr)
		3.47×10^7	402 (48 hr)	5.51×10^7	638 (48 hr)
	30,000	3.47×10^7	1,608 (24 hr)	5.51×10^7	2,551 (24 hr)
		6.95×10^7	804 (48 hr)	1.10×10^8	1,276 (48 hr)
	26,597 *	2.54×10^7	1,190 (24 hr)	3.80×10^7	1,759 (24 hr)
		5.14×10^7	595 (48 hr)	7.60×10^7	880 (48 hr)

*Milwaukee River Basin area

Metric conversion

acres x .405 = ha
ft^3 x 28.32 = liters
ft^3/sec x 28.32 = ℓ/sec.

it is likely that the land available for the purpose of UR storage is quite small. The land which is vacant is likely to be utilized for urban development projects, parks and recreation facilities or parking lots. The placement of UR storage facilities on property which might be otherwise utilized could raise serious public objections.

Treatment Processes

Various types of treatment processes may be used to control UR. In general, physical-chemical treatment processes are more applicable than biological processes for several reasons. When biological treatment processes are used, they must be located near existing dry-weather treatment plants which can supply a continuous active biomass needed for effective intermittent operation. Since UR overflow sites are often distributed throughout an urban area, a centrally located treatment site may not be feasible. The intermittent nature of storm events also makes automatic startup and shutdown of the treatment process an essential feature. Physical/chemical treatment

TABLE 15. AREA REQUIREMENTS FOR DIFFERENT STORAGE VOLUMES*

Design storm	UR area, acres	Pump-out time, hrs	Area for UR storages, acres 1 yr. storm	Area for UR storages, acres 5 yr. storm
1 hr duration	7,850	24, 48	24.9	38.4
	15,000	24, 48	47.6	73.3
	30,000	24, 48	95.3	146.6
	26,597**	24, 48	82.0	116.3
24 hr duration	7,850	24	13.9	22.0
		48	27.9	44.0
	15,000	24	26.6	42.2
		48	53.1	84.3
	30,000	24	53.1	84.3
		48	106.4	168.4
	26,597	24	38.9	58.2
		48	78.7	116.3

*Assuming a 15' depth
**Milwaukee River Basin

Metric conversion:

acres x 0.405 = ha
ft x 0.305 = m

lends itself to automation much more readily than biological treatment. Finally, the lower organic content of solids associated with UR makes physical/chemical treatment more attractive than biological treatment processes which utilize an organic substrate.

Various physical/chemical treatment processes have been shown to be applicable to treatment of CSO. Less information is available on performance and operation of potential treatment processes with UR. However, since many of the characteristics of UR are similar to CSO characteristics, it is believed that physical/chemical treatment processes proved applicable to CSO treatment could be utilized for UR treatment.

The six treatment processes considered in this evaluation were:

1. Storage/Sedimentation
2. Screening/Dissolved Air-Flotation
3. Microscreening
4. Screening/Filtration
5. Chemical Sedimentation
6. Swirl Concentration

The effectiveness of treatment and sludge volumes produced varies significantly with the different treatment processes. All of the processes except swirl concentration require some type of preliminary storage/equalization. This will dampen the shock loads associated with UR as well as allowing the treatment processes to operate at higher efficiencies. Because no data is available on the removal efficiencies of sequential processes, the storage system has been assumed to be a completely mixed basin which provides flow equalization but no treatment. The entire pollutant load is then handled in the subsequent processes. In this way, published removal efficiencies for each treatment method could be applied.

Land area needs for treatment processes are not anticipated to contribute to the total area requirements for several reasons. When storage systems precede treatment, they are usually located underground, with the treatment units mounted above them. Therefore, no additional area is needed for the treatment processes. Finally, if storage/sedimentation is involved, no additional area is needed since both retention and treatment are accomplished in one step.

SLUDGE VOLUME AND CHARACTERISTICS

Assumptions Used in the Calculations

Because UR sludges were not field characterized under this effort, it was necessary to calculate the anticipated sludge volumes and characteristics. This first involved definition of average or typical UR characteristics. These data have been presented (Tables 10,11 and 12): Then it was necessary to calculate or estimate the anticipated sludge volumes and/or sludge concentrations. These were based on the percent removals for suspended solids plus either sludge volumes or concentrations which were assumed to be the same as those reported for combined sewer overflow sludges. A list of the estimates and calculated values for a national average of UR sludge is included in Table 16. From knowledge of the sludge volumes plus removal efficiencies for other parameters, it was possible to predict the other sludge characteristics. These assumptions are summarized in Table 17. It should be noted that this approach reflects the most accurate information available when the report was prepared. Updated removal efficiencies may be available for more recent publications. An example of this exists with regard to the swirl concentrator. Percent removals of suspended solids may be reduced and sludge volume increased according to more recent studies and these data will directly affect the impact of using a swirl device for UR treatment.

Since data were not available regarding metal removal efficiencies, it was assumed that only the insoluble fraction of the metal was removed in the same proportions as the suspended solids removals. Information regarding the soluble/insoluble fractions of the metals on a national level was extrapolated from the actual data available from UR sampling and analyses performed in the Milwaukee area.

TABLE 16. SLUDGE VOLUME AND PERCENT SOLIDS (NATIONAL BASIS)

Treatment process	Percent removal	Influent SS (5) mg/l	% Solids in sludge	Volume sludge % of influent flow
Storage/sedimentation	87[a] (10)	415	12.0	0.3 (11)
Screening/DAF	65 (1)	415	0.58	4.8 (11)
Microscreening	73 (1)	415	0.51	6.0 (11)
Chemical sedimentation	68 (1)	415	2.0 (12)	1.4
Screening/Filtration	65 (1)	415	1.4	2.0 (13)
Swirl concentration	60 (1)	415	0.85	3.0 (14)

Numbers in parentheses indicate reference numbers.
a - includes removal by storage

TABLE 17. POLLUTANT REMOVAL EFFICIENCIES FOR VARIOUS TREATMENT PROCESSES

Treatment process	Percent removals			
	BOD	COD	TP	TKN
Storage/sedimentation	50 (10)	47 (10)	39 (10)	86 (10)
Screening/DAF	50 (1)	55 (1)	55 (1)	35 (1)
Microscreening	30 (1)	35 (1)	20 (1)	30 (1)
Chemical sedimentation	68 (1, 15)	45 (1)	46 (2)	55 (2)
Screening/Filtration	60 (1, 15)	40 (1)	50 (1)	21 (1)
Swirl concentration	30*		25*	25*

Numbers in parentheses indicate reference numbers.
* Assumed value.

It is important to note the high efficiencies of removal associated with storage/sedimentation. Compared to other, more sophisticated treatment processes, this technique is very effective. The main reason is the long detention time through the storage system. At a 24-hour storage time, the removal rate for suspended solids reaches 87 percent due to the nearly total capture of the overflow volume. The long storage also allows compaction of the solids into a much smaller volume for final removal. The major disadvantage of this approach appears to be the large surface area requirement for treatment.

Sludge Volumes

Many different variables impact both the volume and characteristics of UR sludges, so the reader is cautioned against utilizing the data for anything but relative comparisons. The sludge volumes calculated from the previously stated assumptions are included in Table 16. Whenever available, these numbers were based on sludge volumes associated with CSO sludges since the authors felt the solids would result in a similar type material. The main difference is the percent solids in the sludge since UR usually has a higher concentration of inorganic suspended materials,which are heavier and easier to separate from the total flow.

The sludge volumes are affected by many variables,including the quality of the UR, the type of treatment process utilized, the detention times through the system and the treatment efficiencies of the processes. An important consideration when evaluating the overall impact of a treatment system is to review the opposing effects of treatment unit efficiency. When a highly effective treatment process is employed,it removes more solids from the influent,and increases their concentration (and impact) from the sludge handling standpoint. The differing influent solids which were found in the evaluation of areas havea significant effect on either the sludge characteristics or volumes,depending upon the basis for calculations.

Sludge Quality

The UR sludge quality associated with different treatment processes was estimated and the results are presented in Tables 18 and 19. To directly compare the sludges associated with the Milwaukee River Basin area and the nationwide sludges, Table 20 was prepared. Two dissimilar sludges from sedimentation and swirl concentration treatment techniques were utilized.

It can be seen that there are significant differences between the solids concentrations for the two sludges. This reflects the different influent UR suspended solids concentrations previously discussed. The higher BOD_5, TKN and total phosphorus values are also indicative of the different influent qualities for the Milwaukee River Basin UR. The metals concentrations did not vary consistently. Because of the differences in metal soluble and insoluble fractions, the trends between the two processes changed. There were no direct relationships. These differences and

TABLE 18. ESTIMATED CHARACTERISTICS OF NATIONAL URBAN RUNOFF SLUDGES

		Treatment process					
Parameter	Units	Sedimentation	Screening DAF	Micro-screening	Chemical sed.	Screening/ Filtration	Swirl concentration
Volume sludge/ volume UR treated	%	0.3	4.8	6.0	1.48	2.0	3.0
Solids	%	12.0	0.58	0.51	2.0	1.48	0.85
BOD_5	mg/kg	27,800	37,600	24,800	48,900	43,400	23,500
TKN	mg/kg	3,370	1,930	1,580	2,800	1,140	1,380
TP	mg/kg	675	1,270	502	1,040	1,130	680
Zn	mg/kg	302	345	352	323	309	305
Al	mg/kg	13,425	15,517	15,921	14,380	14,186	14,682
Ca	mg/kg	4,028	5,235	4,784	4,309	4,242	4,400
Co	mg/kg	159	181	189	169	170	176
Cr	mg/kg	168	189	196	458	175	188
Cu	mg/kg	252	293	294	268	268	259
Fe	mg/kg	10,067	11,500	947	10,781	10,640	1,180
Pb	mg/kg	251	293	294	267	268	259
Mg	mg/kg	8,392	9,586	9,941	8,986	8,866	9,165
Mn	mg/kg	563	638	667	602	593	612
Ni	mg/kg	126	143	69	133	134	129
Cd	mg/kg	21	24	25	22	22	21

TABLE 19. ESTIMATED CHARACTERISTICS OF MILWAUKEE RIVER BASIN URBAN RUNOFF SLUDGES

		Treatment process					
Parameter	Units	Sedimentation	Screening/ DAF	Micro-screening	Chemical sed.	Screening/ Filtration	Swirl concentration
Volume sludge/ volume UR treated	%	0.3	4.8	6.0	0.53	2.0	3.0
Solids	%	4.5	0.218	0.194	2.0	0.730	0.318
BOD_5	mg/kg	75,267	182,100	117,525	257,243	236,986	125,785
TKN	mg/kg	11,467	6,559	5,309	9,380	3,698	4,717
TP	mg/kg	2,511	4,770	1,855	3,797	4,315	2,280
Zn	mg/kg	455	449	460	388	293	421
Cu	mg/kg	64	778	118	103	80	314
Fe	mg/kg	5,511	2,828	2,489	2,102	1,600	2,327
Pb	mg/kg	75	280	288	243	183	135
Cd	mg/kg	7.7	53	55	46	36	17

TABLE 20. COMPARISON OF NATIONAL AND MILWAUKEE RIVER BASIN UR SLUDGE QUALITY

		Sedimentation		Swirl concentration	
Parameter	Units	National	Milwaukee River Basin	National	Milwaukee River Basin
Volume sludge/ volume UR treated	%	0.3	0.3	3.0	3.0
Suspended solids	%	12.0	4.5	0.85	0.318
BOD	mg/kg	27,800	75,267	23,500	125,785
TKN	mg/kg	3,370	11,467	1,380	4,717
TP	mg/kg	675	2,511	680	2,280
Zn	mg/kg	302	455	305	421
Cu	mg/kg	252	64	259	314
Fe	mg/kg	10,067	5,511	1,180	2,327
Pb	mg/kg	251	75	259	135
Cd	mg/kg	21	7.7	21	17

variations further highlight the importance of evaluating both UR and the associated sludge characteristics on a site-specific basis.

Comparison and Evaluation of Sludge Characteristics

In order to provide a basis of comparison to other types of treatment plant residues, Table 21 has been prepared. The national UR sludge values as calculated have been compared to the qualities and quantities of raw primary and combined sewer overflow sludges. The results indicate that, depending on the treatment method, the volume of UR sludge can exceed both the volume of raw primary or CSO sludges which must be handled. The weight of solids for disposal exceeds both,due to the large amount of grit found in UR sludges.

With respect to other parameter concentrations, the differences are not as well defined. The large ranges of values result in overlap for most categories. Metals concentrations in the UR sludges appear to be on the low end of the range. Chromium values are somewhat higher and zinc concentrations are lower than in CSO sludges, however, both variations are direct functions of the soluble/insoluble metal fraction which must be defined on a site-specific basis. The nutrient concentrations are generally lower for UR sludges than CSO sludges and significantly less than raw primary sludges.

Some of the critical characteristics of the UR sludges cannot be quantified in a tabular form and it is difficult to assess the long term impact. One of the most critical aspects is the high concentration of grit or other heavy inert solids in the sludge. These materials could adversely affect operation of biological and some physical/chemical treatment processes. The low ratio of volatile solids to total solids indicates that the amount of biodegradable material is low and this, as well as the low concentrations of nutrients in the sludge, will also negatively impact biological treatment.

From this information, it can be seen that although the treatment of UR significantly reduces its immediate environmental impact, there are many additional impacts to be considered and evaluated. The remainder of this report presents some of the critical impacts,with emphasis on both the primary and secondary effects of handling the sludges generated from various UR treatment processes.

TABLE 21. CHARACTERISTICS OF UR, CSO, AND PRIMARY SLUDGES

Parameter	Units	UR*	CSO (16)	Primary
Volume	m^3/year	8.78×10^6 - 175×10^6	156×10^6	60.9×10^6
Dry solids	metric ton	7.46×10^6	1.67×10^6	2.88×10^6 (17)
Sludge production	m^3/Mm^3	3,000-60,000	2,000-200,000	2,440-3,430 (18)
TS	%	0.51-12.0	0.3-6	2-7 (19)
Phosphorus as P	mg/kg	502-1,270	2,800-7,400	3,500-12,200 (21)
TKN	mg/kg	1,140-3,370	1,100-13,000	15,000-40,000 (21)
Zinc	mg/kg	302-352	697-7,154	900-8,400 (20)
Lead	mg/kg	251-294	164-2,448	150-26,000 (20)
Copper	mg/kg	252-294	200-2,454	200-1,740 (20)
Nickel	mg/kg	69-143	83-995	44-740 (20)
Chromium	mg/kg	168-458	52-2,471	66-310 (20)

* All UR values referenced from Table 18.
Numbers in parentheses indicate reference numbers.

SECTION 6

EVALUATION OF THE IMPACTS OF BLEED/PUMP-BACK OF URBAN RUNOFF SLUDGES

INTRODUCTION

When evaluating the various alternatives available for handling the sludges generated by UR treatment, one of the most attractive approaches involves bleed/pump-back of the sludges to the dry-weather treatment plant. To accomplish effective bleed/pump-back, sludges would be temporarily stored at the satellite treatment site and then carefully released into the sanitary sewer for eventual treatment at the dry-weather plant. There are several advantages to this approach including 1) a sludge transportation system is already in existence, 2) the sludge would be handled at one central location by experienced personnel, and 3) the timed addition of these sludges to a dry-weather influent could aid in overall equalization. However, there are also important disadvantages to the approach. Among these considerations are 1) the high probability of grit deposition in the sanitary sewers, 2) the differing nature of sludges with respect to normal sanitary sewage, and 3) the strong potential for overloading treatment plants which may already be operating at capacity. This section presents some of the critical impacts which must be evaluated when the alternatives of bleed/pump-back of sludges and the residuals from sludge dewatering are assessed.

GENERAL CONSIDERATIONS

The impacts of bled/pumped-back sludge or effluent from the dewatering of sludges can be evaluated in several ways. One method is to calculate the actual loading caused by bleed/pump-back on an average treatment plant. The impact on both the dry-weather treatment plant processes and sludge handling equipment can then be quantified. This approach has been utilized later in this section. There are also other considerations which must be addressed, however, most of these are more qualitative in nature. Among these are: the basic quality of the sludges or residuals being bled/pumped-back and their impact on effective treatment plant operation; potential problems associated with bleed/pump-back of a gritty sludge through sanitary sewers; the difficulties in equalizing plant influent by using sludge; and the limited availability of excess capacity at dry-weather treatment plants. A similar evaluation was performed in order to assess the impact of handling combined sewer overflow (CSO) sludges (11). The results of this study are pertinent to this discussion and are briefly summarized.

Evaluation of Bleed/Pump-Back of CSO Sludges

The problems associated with the handling of sludges generated from CSO treatment are in many ways similar to those encountered for UR. In a separate report (11), the impact of bleed/pump-back of CSO sludges was assessed. The eight conclusions drawn are as follows:

1. The more excess capacity available at the dry-weather plant, which are functions of peak:average dry-weather flow, and built-in safety factors, the more feasible is bleed/pump-back of CSO sludges.
2. Bleed/pump-back of CSO sludges would involve the lowest cost due to reduced transportation and use of existing dry-weather facilities for handling. However, this alternative has inherent disadvantages which make the procedure generally not applicable.
3. Bleed/pump-back will not be possible unless sufficient scouring velocity can exist in the individual sewer interceptors to prevent accumulation of grit in the lines. Excessive grit deposition in the sewer can cause odor and septicity problems,and if flushed to the plant,can adversely affect normal operation.
4. The direct bleed/pump-back of CSO sludges or the effluents from on-site dewatering of CSO sludges will have an effect on both the dry-weather treatment plant and the sludge handling facilities. These impacts can be considered separately.
5. Impact of bleed/pump-back of CSO sludges on the dry-weather treatment plant has been evaluated with respect to hydraulic, solids (primary and secondary), organic and toxic materials loadings to the various processes. Bleed/pump-back of the sludge over a 24-hour period, although desirable from a standpoint of limited storage and reduction in septicity, is not possible in most instances because to do so would unduly overload the dry-weather plant.
6. The limiting factor to consider is the solids loading to the final clarifier,in order to prevent final effluent deterioration. Calculations indicate that bleed/pump-back periods of 8 to 22 days are necessary depending upon the CSO treatment method involved.
7. Bleed/pump-back of CSO treatment sludges directly to the dry-weather sludge handling facilities over a 24-hour period will overwhelmingly overload facilities hydraulically, solids-wise and organically. These gross overloads will be expected to detrimentally affect the dewatering and stabilization performance and treatment efficiency of the dry-weather sludge handling facilities. The down-grading in treatment efficiency would be manifested in poorly stabilized sludge for disposal, and grossly deteriorated thickener effluents, filtrates, supernatants, etc., for recirculation back to the dry-weather treatment plant.

8. Disadvantages of bleed-pump-back also include the adverse effect on the operation and efficiency of the dry-weather plant, caused by loading the plant at excessive levels constantly, and the difficulty in storing CSO residuals without stabilization for any excessive length of time.

The results indicate that bleed/pump-back of CSO treatment sludges is generally not a feasible solution due to problems associated with grit deposition during transport as well as solids overload to the treatment plant itself. It should be recognized that UR treatment sludges will have many of the same problems. In addition, the difficulties may be compounded since combined sewer overflow and UR treatment must be performed concurrently. If a city sewer system includes both combined and separate sewers, then the effects from bleed/pump-back of treatment sludges are additive. If CSO sludges bleed/pump-back alone is not an acceptable alternative in most situations, then the UR sludges effect will increase the associated problems. For this evaluation, however, the UR sludge impact on the dry-weather plant has been considered separately. Therefore, it must be understood that if a complete evaluation of a specific site is performed, the impact from both UR and CSO sludges must be considered.

Quality Considerations

The quality of UR sludges has been presented in detail in Section 5. However, there are certain aspects of the sludge quality which must be highlighted when evaluating the feasibility of bleed/pump-back. The most important consideration is that any sludge is significantly different in quality than a typical wastewater. This sludge contains large amounts of the materials which are to be removed at a treatment plant. Initial concentration of these contaminants has taken place during the storage/treatment processes and the sludge has already become "old" before it is mixed with the normal dry-weather flow. It is this aging as well as the high concentrations of gritty suspended solids that make the bleed/pump-back of UR sludge more than a simple matter of dilution to reach acceptable concentration levels. The nature of the contaminants are either initially different or changed when handled. This difference can have a significant adverse effect on the dry-weather plant operation. If the gritty solids can be transported to the plant, they will place a large additional load on all treatment processes which are affected by solids loading. These include the grit chambers, primary sedimentation basins and final clarifiers as well as the sludge handling facilities. The grit is also much more difficult to handle and requires special considerations throughout the treatment system. A calculation of the solids loading, in terms of excess weight, will not indicate the nature of this problem.

The quality of the sludge can also affect the efficiency of the secondary plant. Microorganisms which have been acclimated to a certain type of sewage may not perform with the same effectiveness when the influent characteristics are different. Physical/chemical operations could also be affected since the optimum chemical dosages are established by the waste characteristics which are different when bleed/pump-back is included. It is this type of impact which is difficult to assess and which makes the bleed/

pump/back alternative questionable.

Transport Considerations

Another potential problem is associated with the use of existing sanitary sewers to transport UR sludge to the treatment plant. These sludges contain a large percentage of grit and heavy solids which were flushed down the sewers in periods of high flow. These solids were removed during the storage of the UR and have accumulated in the sludge. When the sludge is bled/pumped-back through the sanitary sewer,there is a strong possibility that the heavier particles will be deposited in the sewers.

This theory is supported by the general criteria used in sewer system design. WPCF Manual of Practice No. 9 states that "commonly, slopes are calculated so that when flowing half-full or full, the velocity will be 0.6 m/sec (2.0 ft/sec) for sanitary sewers, or 0.9 m/sec (3.0 ft/sec) for storm sewers." From this general approach plus the use of Camp's formula for velocity calculation, it is apparent that the storm sewer will suspend and transport larger and heavier particles. When the same material is discharged into the sanitary sewer, some of the heavier or larger grit will have a tendency to be deposited on the bottom of the sewer. The problem can be further compounded if sludge is bled/pumped-back during periods of low flow when the velocity may be even less.

If gravity flow transport is not possible, then forced flushing may be necessary to prevent problems associated with the accumulation of unstabilized sludge solids on the bottoms of sanitary sewers. This flushing would again affect the quality of the influent flow to the treatment plant which may be detrimental to normal operations. Therefore, it can be concluded that transportation of UR sludges through the sewer system can cause serious problems. If sufficient scouring velocity is not available in the sanitary sewers, the advantages associated with bleed/pump-back are severely reduced. When the alternative of bleed/pump-back is evaluated for a specific site, the slopes of the sewers to be used must be determined as well as the characteristics of the UR sludge solids. From this information, the potential for deposition can be determined and its severity evaluated.

Loading and Flow Equalization

Typical wastewater treatment plant flows exhibit diurnal variations in various degrees. Flows and contaminant strengths are both affected. General relationships commonly used to estimate flows from areas of moderate size are (22):

Maximum daily flow = 2 x average daily flow
Maximum hourly flow = 1.5 x maximum daily flow or
3 x average daily flow
Minimum daily flow = 2/3 x average daily flow
Minimum hourly flow = $\frac{1}{2}$ x minimum daily flow or
1/3 x average daily flow

These variations are common in almost all wastewater treatment plants. However, improved efficiency and control are possible if treatment processes are operated at more uniform conditions (23). It seems possible that bleed/pump-back of sludges could be done to aid in the equalization process. However, this approach would be very difficult to implement from numerous satellite treatment sites. In addition the volumes of flow associated with sludge are low while the concentration of contaminants is high. Equalization would, therefore, be difficult to implement and the sludge bleed/pump-back would probably not provide an effective approach.

Plant Capacity Considerations

Dry-weather treatment plants are developed with certain empirical safety factors included in the design criteria. These factors are utilized to account for normal flow variations, as well as the typical growth pattern anticipated for an urban area. In addition, since the specific nature of the waste is unknown, the design must be conservative in order to assure, as much as possible, treatment to the required levels.

The degree of safety designed into the treatment plant will vary. Table 22 shows typical design variables which are utilized. It can be seen that some plants may be capable of handling 1.5 to 4 times the average of design loading. However, constant operation at very high volumes or loadings adversely affects the final effluent quality. Most effluent requirements are defined as an average, so that the benefits of low flow -efficient operation can counterbalance the effects of high capacity operations. Therefore, an increase in loading parameters could significantly reduce the effluent quality.

TABLE 22. SEWAGE TREATMENT PLANT DESIGN FACTORS (11,22)

Parameter	Average amount	Design factor	Maximum amount	Capacity available
Flow	17.14×10^6 m^3/day	1.5-3	$25.7\text{-}51.4 \times 10^6$ m^3/day	8.57×10^6 m^3/day
Solids - primary	3.43×10^6 kg/d	1.5-3	$5.1\text{-}10.3 \times 10^6$ kg/d	1.7×10^6 kg/d
Solids - secondary	1.37×10^6 kg/d	98-146 kg/d/m^2	2.04×10^6 kg/d	0.67×10^6 kg/d
Organic - secondary	2.3×10^6 kg/d	0.35-0.50 kg/kg MLSS*	3.29×10^6 kg/d	0.99×10^6 kg/d

* MLSS = Mixed liquor suspended solids

It must also be remembered that many urban area treatment plants have already been operated for most of their design lifetime. Therefore, the safety factor associated with normal flow increases has been significantly reduced or eliminated. These plants may already be operating at the edge of their design limitations and the impact from bleed/pump-back of UR sludges could cause severe overloading.

The evaluation included in this section assumes that the dry-weather treatment plant is operating with a large safety factor of capacity available. This approach allows the alternative of bleed/pump-back to be evaluated as fairly as possible. However, it must be remembered that actual assessment of the bleed/pump-back impacts must be based on the operating conditions at the specific dry-weather treatment plant as well as the volumes of UR sludge generated in that area. Only after this individual approach is complete can the feasibility of bleed/pump-back be established for a specific site.

BASIS FOR DETERMINATION OF IMPACTS

In order to establish the calculated impact of bleed/pump-back of UR sludges, many assumptions are required. Since it is not possible to evaluate site-specific impacts, a generalized nationwide impact has been determined. Some of the considerations addressed previously, such as quality and transport problems plus operational problems caused by high loadings will not be considered in this part of the evaluation. Instead, the calculated impact of bleed/pump-back of sludge and residuals from sludge dewatering will be addressed separately from the standpoint of hydraulic, solids, organic and toxic loadings on the treatment plant.

Treatment Plant Assumptions

The impact of bleed/pump-back of the UR sludges was calculated on a nationwide basis assuming a hypothetical dry-weather treatment plant which handled the sewage generated by the average urban area sewered population in the United States. A typical secondary treatment plant having the unit processes shown in Figure 7 was utilized to assess impacts. This type of plant is in common use today and has the capability of meeting most long range effluent standards.

The associated sludge handling system, which will be greatly impacted by the increased solids loading from UR sludges, is pictured in Figure 8. The use of gravity thickening, anaerobic digestion stabilization, followed by vacuum filter dewatering, will be considered in this evaluation.

It was assumed that the sewered population served by the hypothetical treatment plant was 340,000. When a population flow equivalent of 473 ℓ/d (125 gal/d) is applied, the average plant capacity was calculated to be 161,000 m^3/d (42.5 Mgal/d). The average BOD_5 and SS concentrations were calculated to be 200 mg/ℓ. Toxic metals concentrations in raw sewage were established from literature values. Plant capacity available for handling the load from UR sludge was based on typical design factors which are summarized in Table 22. In addition it was assumed that 60 percent of the suspended solids and

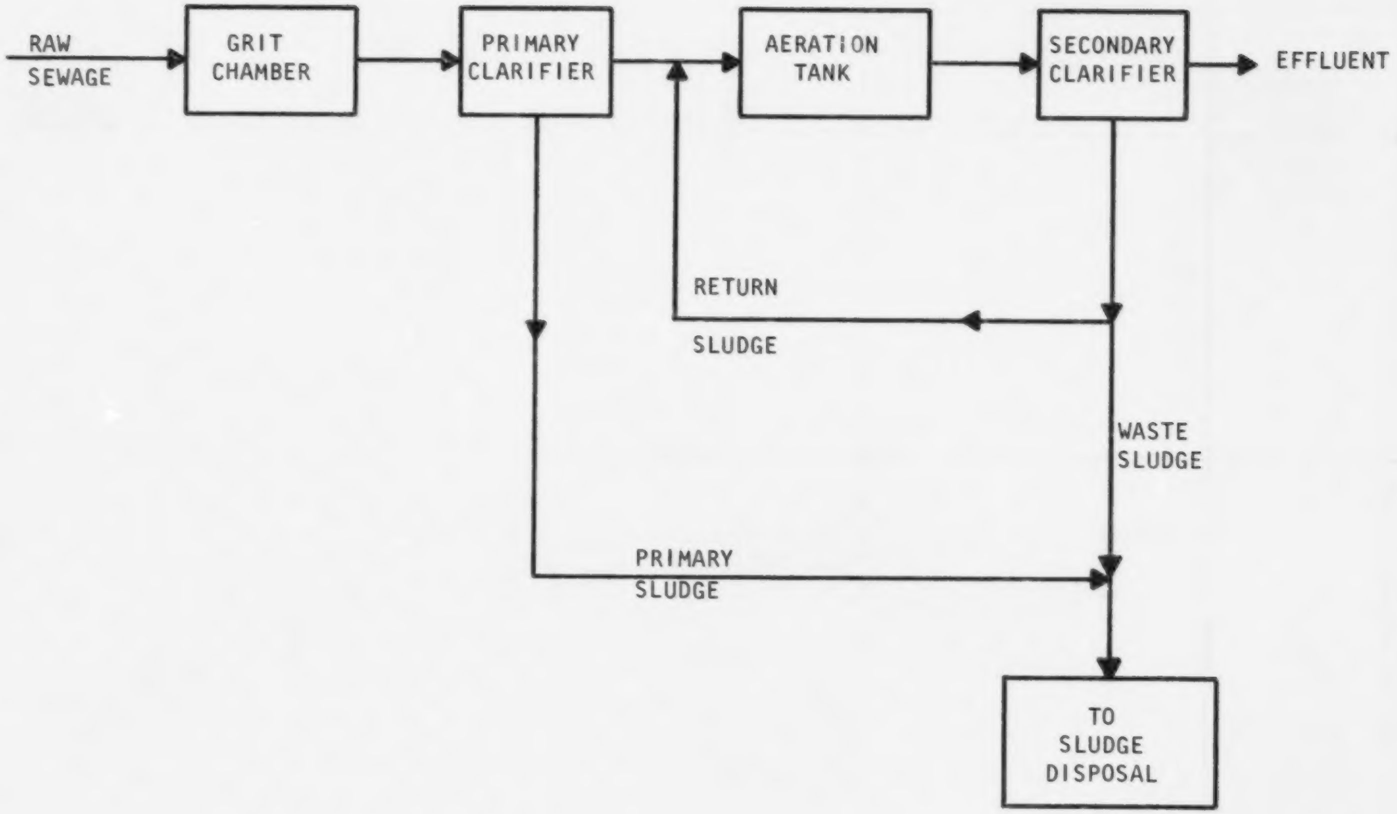
RAW
SEWAGE
GRIT
CHAMBER
PRIMARY
CLARIFIER
AERATION
TANK
SECONDARY
CLARIFIER
EFFLUENT
RETURN
SLUDGE
WASTE
SLUDGE
PRIMARY
SLUDGE
TO
SLUDGE
DISPOSAL

Figure 7. Conventional activated sludge plant.

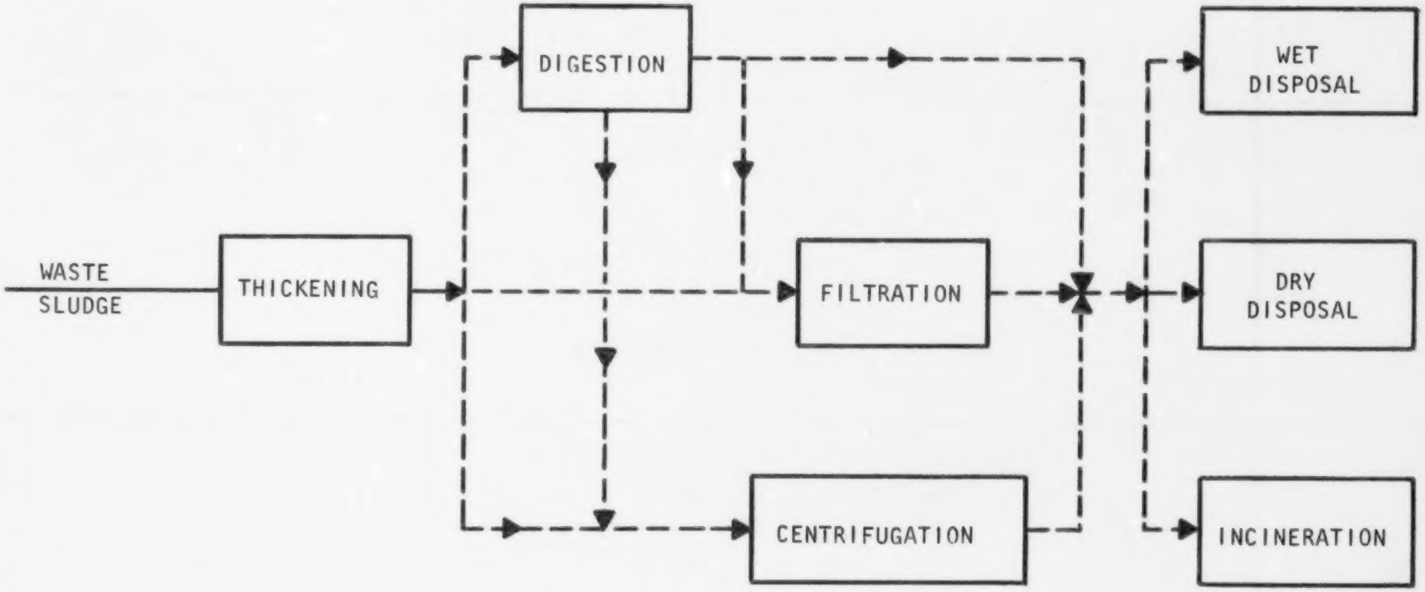
WASTE SLUDGE
THICKENING
DIGESTION
FILTRATION
CENTRIFUGATION
WET DISPOSAL
DRY DISPOSAL
INCINERATION

Figure 8. Schematic diagram of the various steps leading to ultimate sludge disposal.

35 percent of the BOD_5 were removed during primary treatment.

Assumptions Used to Calculate Sludge Bleed/Pump-Back Impacts

Sludge quantities and qualities as presented in Section 5 were used in calculating the final impact of sludge bleed/pump-back. The impacts of sludge bleed/pump-back from storage sedimentation and swirl concentration were evaluated to provide a range of impacts from various types of sludge. It was assumed that the sludge would be stored on-site and bled/pumped-back to the treatment plant uniformly over a 24-hour period. Due to the many difficulties associated with timed sludge bleed/pump-back of sludges, it was felt an impact could not be accurately determined.

When the impact of UR sludge bleed/pump-back on the sludge handling facilities was investigated, it was assumed that the sludge was transported to the treatment plant separately and mixed directly with dry-weather sludge at the gravity thickener. Due to the previously mentioned problems associated with transport of sludge, and the concentration/re-concentration effects, this approach seemed feasible. In addition, since the impact of the sludge on these processes is controlled by solids loading, the location of sludge introduction does not significantly affect the design parameters (assuming that most of the sludge would be removed in the treatment plant).

Assumptions Used to Calculate Residual Bleed/Pump-Back Impacts

The assessment of the impact of residuals from on-site dewatering on the dry-weather plant required several additional assumptions. Residuals were considered to consist of thickener supernatant and filtrate from vacuum filter dewatering. The estimated characteristics of these residuals were based on experience with municipal sludge dewatering. The volumes of residuals were calculated assuming 5000 mg/ℓ suspended solids in the gravity thickener supernatant and 5 percent SS in the thickened sludge, as well as 400 mg/ℓ SS in the vacuum filtrate and 20 percent suspended solids in the dewatered sludge (24). Additional information on supernatant and filtrate quality was not available in the literature. Therefore, only the hydraulic and solids loading impacts from the bleed/pump-back of thickening and dewatering residuals on the dry-weather plant were evaluated.

The sludge thickening and dewatering at the satellite site were assumed to occur over a 48-hour period. A 48-hour time allowed reasonable loading rates on the thickening and dewatering units and minimized problems associated with overlapping storm events. It was assumed that the supernatant and filtrate would be continuously pumped back to the dry-weather plant over the 48-hour period.

IMPACT EVALUATION

Sludge Bleed/Pump-Back

Impact on the Dry-Weather Treatment Plant--

The magnitude of the impacts of UR sludge bleed/pump-back on the dry-weather treatment plant was calculated and is summarized in this discussion. Table 23 presents the percent overload and the days required for bleed/pump-back of the two sludge types investigated. The percent overload is calculated as a percentage of the loading from the UR sludges to the average loading during dry-weather operation. The safety factors used in design of the composite dry-weather plant provide allowable increases without overloading the treatment processes. (See Table 22 for available capacities.) This allowable additional loading was then used to determine the number of days required for bleed/pump-back of sludge without overloading the dry-weather plant.

Table 23 shows that significant solids overloads would occur in the primary sedimentation basins and final clarifiers if sludges were bled/pumped-back over a 24-hour period after a storm event. The limiting number of days for bleed/pump-back is associated with the solids loading on the final clarifiers and ranges from 2.8 to 3.9 days. The impracticality of bleed/pump-back periods of two or more days is apparent mainly since the sludge is not stabilized prior to bleed/pump-back and also since the possibility of overlapping rainfall events increases with time. Overlapping rainfall events only compound the problems associated with bleed/pump-back.

TABLE 23. PERCENT OVERLOAD AND DAYS REQUIRED FOR BLEED/PUMP-BACK OF UR SLUDGES

	Treatment process	
Loading	Sedimentation	Swirl concentration
Hydraulic		
Percent*	0.33	3.27
Time**	<1	<1
Solids		
Primary		
Percent	196	139
Time	3.9	2.8
Final Clarifier		
Percent	196	139
Time	3.9	2.8
BOD		
Percent	5.46	5.61
Time	<1	<1

* Percent overload = $\frac{\text{Loading from UR}}{\text{Average loading dry-weather flow (DWF)}} \times 100$

** Days to bleed/pump-back based on average design loading, multiplied by the appropriate safety factor.

Another way to illustrate the magnitude of the impact on the dry-weather treatment plant is to use population equivalents to express the volume and strength of the UR sludges. Table 24 lists the equivalent populations based on sludge volumes, weight of solids, and weight of BOD. It can be seen that the largest impact is caused by the heavy solids loading in the sludge. Both the volume and organic impact are much less. Use of these population equivalents shows that additional facilities associated with 224,000 to 316,000 people would be needed to handle the impact of UR sludge bleed/pump-back on an average system which serves 340,000. It can be seen that treatment of UR could double the needed size of the treatment facility.

TABLE 24. POPULATION EQUIVALENTS* OF UR SLUDGES

	Treatment Process	
	Sedimentation	Swirl Concentration
Sludge		
Flow rate, Mgal/d	0.139	1.39
Solids, mg/ℓ	120,000	6,500
BOD, mg/ℓ	3,340	343
Population Equivalent		
Flow rate	1,110	11,100
Solids	$0.316x10^6$	$0.224x10^6$
BOD	22,800	4,530

* Population equivalents

Parameter	Equivalent	Reference
flow rate, Mgal/d	125 gal sewage/capita-day	21
Solids, mg/ℓ	0.44 lbs/capita-day	21
BOD, mg/ℓ	0.17 lbs/capita-day	22

Metric conversion: Mgal/d x 3784.32 = m^3/d

Toxic substances, such as heavy metals, may be present in sufficient quantities to negatively impact the operation of the dry-weather plant, even if there is sufficient capacity to allow bleed/pump-back without overloads. Any toxic materials would have the most impact in the secondary treatment portion of the dry-weather plant. Heavy metal concentrations which could be toxic to biological treatment processes are presented in Table 25. Typical heavy metal concentrations in municipal sewage are presented in Table 26. The concentrations of the heavy metals chromium, copper, cobalt and nickel in UR sludges (Table 27) exceed the toxic level. The concentration of zinc in storage/sedimentation sludge also exceeds the toxic level. However, the metals concentrations are significantly reduced (Table 28) when the UR sludges are blended with municipal sewage, as would occur during bleed/pump-

TABLE 25. TOXIC CONCENTRATIONS OF HEAVY METALS FOR BIOLOGICAL TREATMENT PROCESSES (mg/ℓ)

Metal	Dose to produce 5-10% reduction in aerobic treatment efficiency	Maximum dose for satisfactory anaerobic digestion
Chromium	10 (25,26,27)	>50 (25,27,29)
Copper	1 (25,26,27)	5 (25,27)
Nickel	1-2.5 (25,26,27,28)	>10 (25,27,28,29)
Zinc	5-10 (25,27)	10 (25,27)
Cadmium	3 (26)	
Cobalt	1 (26)	
Lead	-	340 (29)

Numbers in parentheses indicate reference numbers

TABLE 26. HEAVY METAL CONCENTRATIONS IN MUNICIPAL SEWAGE (mg/ℓ)

Metal	Range	Avg.	Reference
Cadmium	0.00075 - 0.021	0.012	(30,31)
Chromium	0.008 - 2.8	0.548	(30,31)
Nickel	0.01 - 0.12	0.056	(30,31)
Zinc	0.20 - 0.79	0.390	(30,31)
Copper	0.04 - 0.25	0.145	(30,31)
Lead	0.03 - 0.92	0.253	(30,31)
Manganese	0.09 - 2.3	0.814	(30,31)
Iron	-	13	(30)

TABLE 27. HEAVY METAL CONCENTRATIONS OF UR SLUDGES (mg/ℓ)

Metal	Sedimentation treatment	Swirl concentration treatment
Zinc	85.6*	6.06
Aluminum	3820	269
Calcium	1140	1140
Cobalt	45.2*	3.20*
Chromium	47.6*	28.1*
Copper	67.0*	48.6*
Iron	3310	2680
Lead	77.3	5.89
Magnesium	2380	168
Manganese	160	11.3
Nickel	35.6*	2.53*
Cadmium	1.68	0.138

* Exceeds critical concentration

TABLE 28. METALS CONCENTRATIONS AFTER BLENDING UR SLUDGE AND MUNICIPAL SEWAGE (mg/ℓ)

Metal	Sedimentation treatment	Swirl concentration treatment
Zinc	0.668	0.570
Chromium	0.701	1.421
Copper	0.363	1.680*
Iron	23.7	97.5
Lead	0.504	0.431
Manganese	1.333	1.146
Nickel	0.172	0.134
Cadmium	0.017	0.203

*Exceeds critical concentration, assuming 60% removal in primary treatment.

back. In this case, only copper in swirl concentration sludges would exhibit a toxic effect, assuming 60 percent removal of heavy metals in primary treatment. The concentrations given in Table 28 were calculated using a bleed/pump-back time of 24 hours. This represents the worst case and metal concentrations would be proportionately lower with lower bleed/pump-back rates. There does not appear to be any potential toxic effects on the dry-weather treatment plant due to bleed/pump-back of UR sludges.

Impact on the Dry-Weather Sludge Handling Facilities--

The impact of bleed/pump-back of UR sludges is not limited to the effect on the dry-weather treatment plant. The sludge handling facilities are also affected by this sludge. Sludge handling facilities are usually designed based upon the estimated sludge produced at average design flow (22).

For the hypothetical dry-weather plant treating an average daily flow of 161,000 m^3/d (42.5 Mgal/d) a primary sludge volume of 393 m^3/d (0.104 Mgal/d) would be handled by the dry-weather sludge handling facilities. The daily design volume (primary plus activated) of sludge to be handled is 3,400 m^3/d (0.90 Mgal/d). The design dry-weather solids to be handled are 49,500 kg/d (109,000 lb/d).

Table 29 illustrates the potential for overloading the dry-weather sludge handling facilities by pumping back UR sludges. Since detention time is one of the important factors in the performance of sludge handling processes, it may be concluded that the large hydraulic overloads associated with bleed/pump-back of UR sludges would significantly and negatively impact their performance. Sludge handling by-products (such as thickener supernatants, digester supernatants, filtrates, centrates, etc) would deteriorate in quality and overload the treatment plant with fine solids, organics, nutrients, etc., when returned to the head end of the treatment plant. The increased solids loading from pumping back UR sludges would substantially overload the sludge handling processes, which were designed based on solids loading, and require 1.5 to 4.5 times additional capacity. The potential for significant overloads and adverse impacts indicate that UR sludge bleed/pump-back directly to the dry-weather sludge handling facilities is not a feasible alternative.

TABLE 29. PERCENT OVERLOAD OF THE SLUDGE HANDLING FACILITIES.

Treatment process	Percent overload* Hydraulic	 Solids
Sedimentation	15.4	128.0
Swirl concentration	154.0	90.4

$$* \text{ Percent overload} = \frac{\text{Loading from UR sludges}}{\text{Average DWF loading}} \times 100$$

Any toxic effect of the heavy metals in UR sludges would be apparent in the digestion processes. Referring to Tables 27 and 28 it can be seen that inhibition of aerobic and anaerobic digestion processes could be caused by high concentrations of copper and zinc in all sludges. Nickel and cobalt concentrations also exceed levels toxic to aerobic digestion processes. However, intermittent handling of sludges containing high heavy metal concentrations in dry-weather digesters has been successfully accomplished in Kenosha, Wisconsin (32). Handling of UR sludges in parallel digester facilities at the dry-weather plant does not appear feasible because essentially no dilution or equalization with dry-weather sludge would occur. If toxicity is a problem, lime stabilization of UR sludges is recommended for rapid on-site or dry-weather treatment plant stabilization.

The increased quantity of sludge solids requiring ultimate disposal must also be considered in the evaluation of impacts. These impacts may include the requirement for additional incinerator capacity, landspreading area, landfill area, etc. The requirement for additional landspreading and landfill area will shorten the useful life of disposal areas presently in use and will make the problem of finding acceptable new disposal sites near urban areas more acute.

Storage/sedimentation sludge bleed/pump-back will produce 63 metric tons (70 tons) per day more sludge (20 percent solids content) requiring final disposal. Bleed/pump-back of swirl concentration sludge will increase the quantity of sludges (20 percent solids) requiring final disposal by approximately 45 metric tons (50 tons) per day. This compares to a total weight of sludge from the dry-weather plant of 272 metric tons (300 tons) per day.

Bleed/Pump-Back of Residuals from On-Site Dewatering

Previous discussion has indicated that bleed/pump-back of UR sludges is not normally feasible. Another alternative is to dewater UR sludges at the satellite treatment facilities (on-site), dispose of the dewatered sludge and bleed/pump-back the residuals from the dewatering processes to the dry-weather treatment plant or sludge handling facilities. The impacts to the dry-weather treatment plant and sludge handling facilities from these dewatering process residuals will now be individually evaluated.

Impact on the Dry-Weather Treatment Plant--

Tables 30, 31 and 32 illustrate the problems associated with pumping back dewatering residuals. As expected, the impact on the dry-weather treatment plant is not as severe as UR sludge bleed/pump-back. The limiting factor was again found to be the solids loading on the final clarifier. The minimum pump-back period for swirl concentration was 2.38 days. Storage/sedimentation has a pump-back period of less than one day and does not appear to pose a problem in this regard.

The population equivalents of the residuals from on-site dewatering given in Table 31 are substantially lower than the sludge population equivalents given in Table 24. Table 32 indicates that in most cases bleed/pump-back of dewatering residuals will not significantly overload the dry-weather plant with regard to the increased volume or solids loading. Data pertinent to evaluat-

TABLE 30. VOLUME AND SOLIDS CONCENTRATION OF DEWATERING RESIDUALS

Treatment process	Raw flow, Mgal/d	Dewatering process*	Residuals Flow, Mgal/d	Residuals Solids mg/ℓ	Residuals Solids No./day
Storage/sedimentation	0.139	F	0.091	400	304
Swirl concentration	1.39	T	1.350	5,000	56,300
		T-F	1.376	4,910	56,300

*T = Gravity thickening
F = Vacuum filtration
Metric conversion: Mgal/d x 3784.32 = m^3/d

TABLE 31. POPULATION EQUIVALENTS OF DEWATERING RESIDUALS

Treatment process	Dewatering process*	Residuals Flow, Mgal/d	Residuals Solids, mg/ℓ	Population** equivalent Flow	Population** equivalent Solids
Storage/sedimentation	F	0.091	400	728	690
Swirl concentration	T	1.35	5,000	10,800	128,000
	T-F	1.376	4,910	11,000	128,000

*T = Gravity thickening
F = Vacuum filtration

** Population equivalents: Flow - 125 gal/capita day
Solids - 0.44 lb/capita day

Metric conversion: Mgal/d x 3784.32 = m^3/d

TABLE 32. PERCENT OVERLOAD TO AN AVERAGE DWF PLANT AND DAYS REQUIRED FOR RESIDUAL BLEED/PUMP-BACK

Treatment process	Dewatering process*	Hydraulic		Primary		Final clarifier	
		%**	Days†	%	Days	%	Days
Sedimentation	F	0.02	<1	0.47	<1	2.00	<1
Swirl	T	3.35	<1	96.5	1.58	372	2.38
	T-F	3.35	<1	96.5	1.58	372	2.38

* T = Gravity Thickening
F = Vacuum Filtration

** $\% \text{ Overload} = \frac{\text{Loading from UR}}{\text{Average DWF loading}} \times 100$

† Days to pump/bleed-back based on maximum loading of design loading times the appropriate safety factor.

ing the significance of the increased organic loading or potential toxicity were not discovered, and therefore, no comment is made at this time.

Impact on the Dry-Weather Handling Facilities--
It appears that the hydraulic and solids loadings to the dry-weather plant from bleed/pump-back of residuals generated by UR sludge dewatering did not pose any significant overloading problems, and bleed/pump-back over a one or two-day period did not seen impractical.

It is also necessary to evaluate the impact of these residuals on the dry-weather sludge handling facilities. Table 33 presents the volume and solids concentration of the residuals from dewatering of UR sludges that would be pumped to the dry-weather plant. Treatment of the residuals will produce an increased quantity of sludge to be handled. The sludges produced were estimated by assuming a primary sludge production of 2240 m^3 (gal) (5 percent solids) per million m^3 (Mgal) of adjusted flow and 18,700 m^3 (gal) (one percent solids) of waste activated per million m^3 (Mgal) of adjusted flow.

TABLE 33. SOLIDS LOADINGS FROM THE TREATMENT OF DEWATERING RESIDUALS

Treatment process	Dewatering process*	lb/d of sludge produced		
		Primary	Activated sludge	Total
Storage/sedimentation	F	167	284	451
Swirl concentration	T	34,200	52,600	86,800
	T-F	34,200	52,600	86,800

* T = Gravity thickening
F = Vacuum filtration
Metric conversion: lb/d x 0.454 = kg/d

It can be seen that the bleed/pump-back of residuals from on-site dewatering of UR sludges would not, in most cases, significantly overload the dry-weather sludge handling facilities. In general, there appears to be no significant impacts on the dry-weather sludge handling facilities associated with pump-back of dewatering residuals when solids or hydraulic loadings are evaluated. The increased quantity of sludge requiring final disposal will negatively impact the sludge disposal facilities. The reduction in useful life of present facilities is one possible effect. As can be seen in Table 34 the additional weight of sludge requiring final disposal from storage/sedimentation sludge dewatering is relatively small. However, dewatering residuals from swirl concentration sludges produce almost the same additional weight of sludge as does sludge bleed/pump-back.

TABLE 34. ADDITIONAL SLUDGE VOLUMES PRODUCED IN TREATING DEWATERING RESIDUALS

Treatment and dewatering process*	Raw influent		Sludge produced		
	Flow, Mgal/d	Concentration, mg/ℓ	Primary, Mgal/d	Secondary, Mgal/d	Total, Mgal/d
Sedimentation (F)	0.091	400	0.0004	0.0034	0.0038
Swirl Concentration (T)	1.35	5,000	0.082	0.631	0.713
(T-F)	1.376	4,910	0.082	0.632	0.714

* T = Gravity thickening
F = Vacuum filtration
Metric conversion: Mgal/d x 3784.32 = m^3/d

Summary

The preceding discussions have shown that, overall, bleed/pump-back of UR sludges to the dry-weather treatment and sludge handling facilities is not a feasible alternative, while bleed/pump-back of residuals from on-site dewatering is a feasible alternative. It must be remembered that conditions producing the least impact were used in the evaluation,and overloads still occurred. This evaluation also did not consider the simultaneous treatment and handling of pumped-back CSO sludges and thereby assumed that the dry-weather plant had greater available capacity than would actually be present. The difficulty in treating sludges with high grit and heavy inorganic solids, and the effect on plant effluent quality must also be considered in the overall evaluation prior to implementation of this handling method.

SECONDARY IMPACTS ASSOCIATED WITH BLEED/PUMP-BACK

Most of the secondary impacts associated with handling UR by bleed/pump-back cannot be quantified except on a site-specific basis. However, generalized impacts can be mentioned so that those evaluating the handling of UR sludges by this method will include these considerations.

Sludge Transportation

Two aspects of sludge transportation should be considered when assessing secondary impacts. The mode of transportation from the UR treatment site to the dry-weather plant can be by sanitary sewer, flushing or truck transport. If gravity sanitary flow is utilized, then grit deposition is a distinct possibility. This would have associated nuisance problems such as odors, plugging of sewer lines with basement flooding, fly accumulation and possibly sewer corrosion. Forced main flushing would be more costly, could cause interference with normal sewer usage, and could disturb quiet neighborhoods during construction. Truck transport has impacts with regard to energy usage, increased heavy traffic on residential streets, and some nuisance or odor problems.

The second need for sludge transportation is from the dry-weather plant to the disposal site. With the increase in sludge to be handled, the impacts associated with disposal of typical dry-weather sludge will be increased. These are discussed in detail in Section 7.

Sludge Disposal

The secondary impacts of sludge disposal can be quite extensive. Increasing the total volume of sludge to be disposed of by approximately 18 to 25 percent will have a significant long range effect on the disposal procedures. The secondary impacts associated with disposal include the increased space needed for the additional sludge volume, possible polluted leachates, runoff, odors, litter, increase in vectors, air pollution, etc. These factors are discussed in more detail in Section 7.

SECTION 7

EVALUATION OF IMPACTS ASSOCIATED WITH URBAN RUNOFF SLUDGE HANDLING AT SATELLITE TREATMENT FACILITIES

INTRODUCTION

If bleed/pump-back does not appear to be a viable method for handling the sludges generated by UR treatment, then other techniques must be utilized. Another alternative involves sludge handling at a satellite or a central treatment site, followed by disposal away from the urban area. Treatment of the sludge on site results in a myriad of both primary and secondary impacts. The primary impacts include the cost of sludge handling and the land area requirements. Secondary impacts include the effect on the final disposal site, as well as increases in the secondary air, water and noise pollution. These different impacts are addressed in the remainder of this section.

SLUDGE HANDLING METHODS

Sludge handling involves several steps including thickening, conditioning, stabilization, dewatering, transporting and disposal. Various conventional processes can be utilized to accomplish these goals. However, due to the unique properties and generation frequency of UR sludges, only some of the processes are suggested for handling these materials.

Sludge Treatment

An in-depth evaluation of sludge handling processes for their applicability to combined sewer overflow sludges was performed elsewhere (11). Since most of the characteristics and problems associated with handling UR sludges are similar, the entire discussion will not be repeated and the reader is referred to this source for additional information.

The extremely high grit content and low volatile solids concentrations associated with UR sludges, as well as their intermittent generation, limits the types of applicable sludge handling processes. Biological systems for stabilization will not be utilized unless an additional substrate is available. Thickening and dewatering techniques can be affected by the high grit content and the heavy suspended solids. Review of available processes indicates that the most applicable processes for sludge handling are as follows:

Conditioning: Chemical treatment
Thickening: Gravity
Stabilization: Lime addition
Dewatering: Vacuum filtration
Pressure filtration

Sludge Disposal

Sludges resulting from UR treatment must, ultimately, be returned to the environment. The available receiving sources are air, land and water. Ocean disposal can be effectively ruled out for UR sludges due to the stringent dumping requirements (40 CFR 220). Land disposal, either by landfilling or by landspreading, is recognized as the method of disposal having the greatest potential for UR sludges. An in-depth study of current and proposed practices in land disposal of sludges was performed elsewhere (33). A summary of the findings as they pertain to UR sludges, is presented herein.

Transportation--

The principal methods of transport to disposal sites are truck, pipeline, barge and rail. Trucking is the most common method of sludge hauling. Flexibility and simplicity of operation are the key reasons for its popularity. Either liquid or dewatered sludge can be loaded into tank trucks or trailers directly from the treatment plant or storage tanks and hauled over most highways to any site or combination of sites. If conditions permit, the sludge can be land disposed directly, eliminating the need for an unloading system at the site. These considerations seem to suggest that truck transport of sludges will be the most viable approach for transporting UR sludges.

Landfill--

Landfilling of sludges is recognized by the U.S. Environmental Protection Agency (EPA) as an environmentally acceptable method of sludge disposal. The placement of UR sludges into fills will generally parallel that used for municipal sludge disposal since the method of landfilling is not altered by waste characteristics. Landfilling practices have been generally classified as trench and area fill. Landfill disposal can be either a sludge-only operation or a co-disposal operation at a sanitary landfill with municipal refuse or sludge. Both types of operation are acceptable. Stabilization may be required prior to landfilling to avoid odor problems. Lime addition will generally be applicable to most plants for partial stabilization and conditioning. Future landfill requirements may specify a minimum of 15 percent dry solids in the sludge to prevent leachate problems, so some type of dewatering may be needed.

Landfilling of UR sludges can create problems that may develop into public health hazards, surface and ground-water pollution, and odor and gas emissions. Leaching of nitrates, toxics, and metal constituents found in UR sludges, into ground waters can have a severe impact on public drinking supplies. Control of leachate production and subsequent treatment will be required where the potential for ground-water contamination exists. The degradation of organics found in sludges can yield innocuous and potentially hazardous gases. Stabilization of the organics will generally be required prior to disposal as will some type of gas collection and dispersion system.

The presence of pathogens in UR sludges might cause disease outbreaks if they contaminate surface or subsurface water supplies. Proper stabilization and/or disinfection in addition to covering the wastes with soil at the end of the working day may be required to alleviate this hazard.

From a recent study, Walsh and Coppel (34) drew some conclusions regarding the most efficient and environmentally acceptable design and operational modes for given sludge characteristics and site conditions. This information, and design considerations suggested in a recent EPA report (35) were used to develop the design basis for determining and evaluating costs for UR sludge landfilling. Table 35 outlines the design parameters and assumptions considered in the sizing of the landfill. The sludge alone, with disposal by the trench method, was selected as means for disposing of UR sludge.

TABLE 35. LANDFILL DESIGN CONSIDERATIONS AND ASSUMPTIONS

Landfill Design: (Trench method, sludge alone)

"In-place" density: 75 lb/ft^3
Ratio sludge/cover material: 3 (TS > 20%) (TS = total solids)
Ratio sludge/cover material: 1 (TS ≤ 20%)
Total landfill depth: 20 ft
Landfill utilization depth: 15 ft
Years of landfill operation: 20
Days of landfill operation: 180/yr
Ratio of total area requirement to usable landfill area: 1.5

Land Requirements

Liquid sludge (TS ≤ 20%)
    408 wet ton/yr/acre
Dewatered sludge (TS > 20%)
    613 wet tons/yr/acre

Landfill Operation

Labor requirements
    1 operator full-time/loader
Fuel requirements
    30 gal fuel/day

Landfill Costs

Land cost: $1,000/acre (no salvage value)
Site preparation cost: $1,275/acre

(continued)

TABLE 35. (continued)

Building cost (trailer w/toilet facility, septic tank, utility hook-up): $9,230
Equipment cost: Crawler loader - <52 kW (<70 hp) $33,225
Crawler loader - 74-97 kW (100-130 hp) $50,625
Contingency: 20% capital cost (excluding land associated costs)
Building utilities cost: $100/mo
Fuel cost: $0.60/gal diesel
Supervision and Administrative cost: 50% of direct labor cost
Labor cost: $6.40/hr
Maintenance: 4% of capital cost (exclude land associated cost)
Taxes and insurance: 4% of capital cost
Capital amortization:
    Crawler loader: 7%
        6 yr life
        15% salvage
Building, etc: 7%
    20 yr life

Metric conversion:

lb x 0.454 = kg
ft^3 x 0.028 = m^3
ft x 0.305 = m
tons x 0.908 = metric tons
acres x 0.405 = ha
gal x 3.785 = ℓ

Landspreading--
Application of sludges to either agricultural or forest lands is also accepted by the U.S. EPA as a viable disposal method. Landspreading of UR sludges to agricultural lands may prove to be a good soil conditioner while conserving and recycling organic matter, nitrogen, phosphorus and certain essential micronutrients. However, proper application is required to avoid potential soil contamination, crop damage, ground-water or surface water pollution,and potential health hazards.

Several different landspreading techniques can be employed at the disposal site. Application of sludges in the liquid state is desirable because of its simplicity. Methods available for surface and subsurface application of liquid sludges include spraying, ridge and furrow irrigation, tank truck spreading, plow-furrow cover or subsurface injection. The most common method is direct application to the land by spraying from tank trucks. When dewatered sludges are applied to the land, the usual method is to spread the sludge on the land followed by plowing the sludge into the soil using farm machinery.

To assure compliance under PL 94-580, the owners and operators of publicly-owned treatment plants must show that the sludge has been appropriately stabilized (36). Stabilization results in a significant reduction of nuisance odors, pathogens and volatile organics. Methods which have produced effective results include composting, biological treatment, chemical treatment, heat stabilization or heat drying. Dewatering processes may be used to reduce the sludge volume and prepare the sludge for transport and disposal. Storage must be provided to hold the sludge until it can be applied to the soil.

Several comprehensive reviews (37 to 40) have addressed the impacts of solids on the soil-plant ecosystem. One physical limitation in sludge application to soils may be the problem of physical clogging of the soil and subsequent loss in infiltration rate (41). Chemical interaction of sludge constituents with the soil-plant system has been the principal area of concern. There are numerous references researching the effects of sludge on soil amendment and plant growth. These studies have basically concluded that nitrogen is likely to affect safe rates of sludge application and these rates will be restricted by the nitrogen requirements necessary for crop production. UR sludges contain an abundance of microelements, i.e., iron, manganese, copper, zinc, molybdenum, etc. Large amounts of these microelements applied to soils may interact and induce deficiencies and/or toxicities. Generally, controlling the loading rate of these metals to the soil will alleviate potential metal contamination problems.

Improper sludge application operations can result in soil-plant contamination, crop damage, surface or ground-water pollution and potential health hazards. Leaching of sludge constituents such as nitrates, toxicants, and metals, into ground and surface waters can have a severe impact on drinking supplies. Leaching can be controlled by proper application rates and soil and crop management. Uncontrolled loading rates can also result in soil toxicities and crop damage. Pathogens may be transmitted by crop consumption, direct contact, runoff, leaching or by insects and rodents if not properly controlled. Additional stabilization and/or disinfection may be required.

It is possible to calculate the field area required for landspreading using the representative characteristics of UR sludge and assuming crop nutrient requirement values. This number should provide rough approximations for determining land area requirements for preliminary planning purposes and should not be used for design or detailed disposal analysis.

The crops selected are corn and orchard grass. Crop yields, fertilizer needs, etc., are presented in Table 36. The annual application rate can be calculated on the basis of nutrient requirements and cadmium loading. Using the method developed by Sommers and Nelson (42), the nitrogen loading constraints for the corn and orchard grass crops are summarized in Table 36. This table also includes the phosphorus application rates. In addition to considering the annual rate of nitrogen application, the annual rate of cadmium must be kept below 2.5 kg/ha/yr (2.2 lb/acre/yr) by 1981 and ultimately below 0.56 kg/ha/yr (0.50 lb/acre/yr) (36). The rate of sludge application to limit cadmium on an annual basis is also shown in Table 36.

TABLE 36. LANDSPREADING DESIGN CONSIDERATIONS

Crop Nutrient Requirements:

Crop	Yield	Nitrogen, lb/acre/yr	Phosphorus, lb/acre/yr	Potassium, lb/acre/yr
Corn	130 bu/ac	170	40	125
Orchard grass	6 ton/acre	300	53	300

Nutrient Loading Constraints:

Case	Crop	Sludge applied, ton/acre/yr	Nitrogen		Phosphorus	
			applied, lb/ac/yr	residual, lb/ac/yr	applied, lb/ac/yr	needed, lb/ac/yr
National, sedimentation	Corn	105	126	44	210	0
National, sedimentation	Orchard grass	185	222	78	370	0
Milwaukee						
sedimentation	Corn	31	124	46	136	0
Swirl	Corn	39	125	45	258	0
Milwaukee						
sedimentation	Orchard grass	56	224	76	246	0
Swirl	Orchard grass	72	230	70	477	0

(continued)

TABLE 36. (continued)

Cadmium-Annual Loading Constraint:

Case	2.0 kg/ha/yr	1.25 kg/ha/yr	0.5 kg/ha/yr
National, tons/ac/yr			
sedimentation	49	31	12
Swirl	52	33	13
Milwaukee, tons/ac/yr			
sedimentation	131	82	33
Swirl	59	37	15

Cumulative Metal Limitations*

Metal	Total metal limit kg/ha	Total amount of sludge allowed (ton/acre)			
		National		Milwaukee	
		sedimentation	Swirl	sedimentation	Swirl
Lead	2,000	4,073	4,352	13,516	12,055
Zinc	1,000	1,696	1,821	1,126	1,246
Copper	500	1,018	1,088	3,982	3,913
Nickel	200	818	875	-	-
Cadmium	20	490	525	1,312	595

*Based on 10 meq/100g

Metric conversions:
lb/ac x 1.121 = kg/ha
ton/ac x 2.242 = metric ton/ha

A comparison of the rates based on nitrogen and cadmium for UR sludges indicates that cadmium application rates will limit the amount of sludge added to soils on an annual basis.

The total amount of sludge that can be applied for the life of a site is based on the cumulative metal additions as calculated from the metal characteristics (Table 18) and limiting loading constraints shown in Table 37.

TABLE 37. TOTAL AMOUNT OF SLUDGE METALS ALLOWED ON AGRICULTURAL LAND

	Soil cation exchange capacity, meq/100g*		
	0-5	5-15	>15
Metal	Maximum amount of metal, kg/ha		
Lead	500	1,000	2,000
Zinc	250	500	1,000
Copper	125	250	500
Nickel	50	100	200
Cadmium	5	10	20

* Determined by the pH 7 ammonium acetate procedure
Reference (42)

Calculations for total sludge loadings for a soil with a cation exchange capacity (CEC) of 10 meq/100g were illustrated in Table 36. This table indicated that cadmium will limit total sludge application to the soil. Using the limiting annual loading rates (cadmium in this case), the site life can be calculated as follows:

	Limiting annual loading rate	Site life
National	26.9 metric ton/ha (12 ton/ac)	40 years
Milwaukee	33.6-62.7 metric ton/ha (15-28 ton/ac)	40 years

Based on these calculations, a 26.9 metric ton/ha/yr (12 ton/ac/yr) rate of UR sludge (on a national basis) is a realistic first approximation for application to agricultural soils. The land area required can be estimated by dividing the quantity of sludge produced by the above values.

Development of Viable Sludge Treatment Schemes

Once the various applicable unit processes have been identified, it is necessary to establish several treatment schemes which can be used to handle UR sludges. Due to the anticipated high concentrations of grit in the UR sludge, it may be necessary to provide grit removal prior to either runoff or sludge treatment. The resulting sludge will then require thickening, stabilization, dewatering and disposal. The optimum treatment scheme utilized at a specific site will depend upon the UR treatment method utilized, the location of the treatment site, land area availability, labor requirements and the ultimate disposal methods utilized.

An evaluation of treatment processes resulted in the identification of six methods for handling UR sludges:

1. Lime Stabilization → Gravity Thickening → Vacuum Filtration → Landspreading.
2. Lime Stabilization → Gravity Thickening → Vacuum Filtration → Landfill.
3. Lime Stabilization → Gravity Thickening → Pressure Filtration → Landspreading.
4. Lime Stabilization → Gravity Thickening → Pressure Filtration → Landfill.
5. Lime Stabilization → Gravity Thickening → Landspreading.
6. Lime Stabilization → Landspreading.

As mentioned, depending on the specific sludge characteristics, it may be necessary to incorporate additional grit removal devices, which could include chain and flight grit removal devices, hydroclones or a special swirl concentrator. Because of the utilization of lime stabilization, additional chemical conditioning has been eliminated. Lime stabilization is simple and effective and will be especially applicable for use with intermittent sludge generation. Two dewatering techniques may be feasible and the final choice will require site-specific treatability work, as well as identification of the disposal requirements. The varying solids concentrations in sludges from these dewatering processes have a significant impact on the hauling and disposal costs. This factor is highlighted when the costs are evaluated. Centrifugation has not been considered feasible due to the high grit content of the sludge.

Disposal requirements vary for each method. Landfilling requires a stabilized and dewatered sludge. Proper site selection and landfill design are essential to prevent surface and ground-water contamination. Landspreading can have more widespread use but also has greater restrictions. The low nitrogen concentration and high metals content make this practice more of a disposal option rather than a resource recovery method. The sludge must be stabilized prior to application. Disposal will be limited to certain times of the year, thus requiring storage facilities. Proper site and crop selection, in addition to controlling the application rates, are key ingredients to successful landspreading operations.

It was felt that the six schemes identified offer the reader a wide choice of applicable techniques to review. They have different primary impacts with regard to both cost and space requirements which are addressed on a general basis in the following parts of this section. However, site-specific determinations are necessary for in-depth evaluation.

PRIMARY IMPACT EVALUATION

Two types of primary impacts were considered in this evaluation. The first involved estimating the costs of the different treatment methods. Land area requirements associated with the different process units were then estimated.

Basis of Cost Estimates

National Estimates--
National costs estimates were prepared based on a series of assumptions and using costs curves when available. Disposal cost data were generated from information presented in the literature (44). The cost curve results were corrected to reflect June, 1977 costs. In order to provide a range of values for cost estimating, the two most dissimilar types of sludges, swirl concentration and storage/sedimentation were considered. The assumptions used in the calculations are discussed in the following paragraphs and it must be emphasized that changes in the assumptions can significantly affect the results.

In order to present the various impacts associated with satellite sludge handling, three groups of urbanized areas were evaluated as indicated in Chapter 5. It was generally assumed that one treatment site served 4050 ha (10,000 acres). It was also assumed that 44 percent of the average rainfall of 91.4 cm (36 inches) was runoff in UR sewered areas (4). Sludge volumes and quantities were established based on information presented in Section 5. For the purpose of these calculations it was assumed that all pollutants concentrated in the thickened and dewatered sludge. A value of 73 events per year (4) was utilized to calculate average loadings per event. Sludge was to be stored on-site and bled through the treatment processes over a 48-hour period. However, due to potential nuisance problems, the sludge was assumed to be lime stabilized within 24 hours. The assumed treatment rates and solids concentrations are presented in Table 38.

TABLE 38. ASSUMPTIONS USED IN NATIONAL COST CALCULATIONS

Process	Treatment rate, hours	Solids concentration, percent solids
Lime stabilization	24	Adds 15% solids
Gravity thickening	48	12
Vacuum filtration	48	35
Pressure filtration	48	45

Sludge storage costs were based on the assumption that a treatment basin costs approximately \$0.26/ℓ (\$1.00 per/gal) of storage volume needed. If the basin was larger than 946.3 m^3 (250,000 gal), then a cost curve was utilized (43).

Operating costs for all systems except lime stabilization were estimated using available curves which presented labor and power requirements (44). Unit costs of \$6.40/hr and \$0.025/kW (45) were used to determine operating and maintenance estimates. Lime stabilization operation and maintenance were assumed to be \$12.40/metric ton (\$11.25/ton) of sludge solids generated (46). All cost figures were calculated on the basis of dry-weight of solids being handled.

Estimation of transportation costs required the use of many different assumptions. These are summarized in Table 39. In addition, it was asssumed that if the UR area was larger than 4,050 ha (10,000 acres) the travel distance to the disposal site was 64.4 km (40 miles) and for area less than 4,050 ha (10,000 acres) the distance was 32.2 km (20 miles). These estimates seemed consistent with the anticipated difficulties in obtaining disposal sites near larger urban areas. Curves were developed incorporating these assumptions and were utilized in the evalution.

Landfill costs curves were prepared based on the assumptions presented earlier in Table 35. Landfill costs were developed for sludge concentrations ≤ 20 percent TS (total solids) and > 20 percent TS. These costs include capital costs (land, area preparation, building and utilities and landfill equipment) and operating costs (labor, supervision, maintenance, taxes and insurance, and power and energy). Landspreading cost curves were based on the assumptions included in Table 40 and design considerations discussed earlier. Landspreading costs included storage, land, site preparation, and spreading equipment.

All costs were updated using appropriate indices to reflect June, 1977 costs. Capital costs were amortized over 20 years at 7 percent interest (47). The capital recovery factor was 0.0944. Annual costs include amortized capital costs, operation and maintenance costs plus a 15 percent contingency amount to cover engineering and planning plus other expenses. Urban land acquisition costs have not been included due to the variations in land costs and availability, as well as the difficulties associated with estimating space requirements.

Milwaukee River Basin Cost Estimates--

Most of the basis of cost calculations were similar to those used for national evaluations with a few exceptions. An annual runoff volume was computed for the three drainage areas contributing to the river basin. The average number of actual events was 69 and it was assumed that the loading was distributed equally per event. Due to the diluted nature of this sludge compared to the national sludge characteristics, different sludge solids concentrations were appropriate. These are summarized in Table 41.

TABLE 39. ASSUMPTIONS FOR ESTIMATING TRANSPORTATION COSTS

Type of transportation

Tank truck - used for thickened sludges
- 2,500 gal
- 3 axle tanker
- 4.5 mpg (diesel)
- 6 year life (600,000 miles)
- 15% salvage value
- $0.25/mile operating costs

Dump truck - used for dewatered sludges
- 10 yards^3
- 2 axle dump
- 4.5 mpg (diesel)
- 6 year life (600,000 miles)
- 15% salvage value
- $0.20/mile operating costs

Time estimations

Speed - 25 mph for 1st 20 miles - one-way
35 mph for 2nd 20 miles - one-way

Loading time - 30 minutes to load
20 minutes to unload

Operating hours - 8 to 22 hours/day

Facilities

- loading and unloading equipment
- dispatch service
- 20 year life

General costs

- fuel (No. 2 fuel oil) $0.60/gal
- labor $6.40/hour

Metric conversions:

gal × 3.785 = ℓ
miles × 1.609 = km
yds^3 × 0.765 = m^3

TABLE 40. LANDSPREADING COST BASIS
(See Reference 33 for details)

Storage - Volume = 0.4 x Annual Sludge Volume

Equipment - Sites require the following:

Big Wheel Tanker - 1,600 gal capacity
diesel fuel
6 year life, 15% salvage

Big Wheel Spreader - 7.2 yard^3 capacity
diesel fuel
6 year life, 15 % salvage

Pay Loader - diesel fuel
6 year life, 15% salvage

Operation

Liquid Spreading - 30 minute self loading
15 minute round trip
Fuel use - 2 gal per trip
Annual operation period - 180 days
Maintenance cost - $10/operating hr

Dewatered Spreading - 30 minute loading (pay loader)
20 minute round trip
Fuel - pay loader: 8 gal/hr
spreader loader: 3 gal per trip
Annual operation period - 180 days
Maintenance cost - $10/operation hr

General Costs

No. 2 fuel - $0.60/gal
Labor - $6.40/manhour
Amortization rate - 7%
Land costs - $1,000/acre if UR area < 10,000 acres
$2,000/acre if UR area > 10,000 acres

Application rates

National - 12 dry tons/acre/yr
40 year life

Milwaukee River Basin
Swirl Treatment - 15 dry tons/acre/year
40 year life
Sedimentation Treatment - 28 dry tons/acre/year
40 year life

Metric conversions:

gal x 3.785 = ℓ
acres x .405 = ha
tons x .908 = metric tons

TABLE 41. ASSUMPTIONS USED IN MILWAUKEE COST CALCULATIONS

	Total handling time, hrs	Swirl, % Solids	Sedimentation, % solids
Lime stabilization	24	0.37	5.2
Gravity thickening	48	5	8
Vacuum filtration	48	25	25
Pressure filtration	48	40	40

Cost Impacts

The capital, operation and maintenance and corresponding annual costs were then calculated for the following six sludge handling alternatives:

Alternative 1 - Lime Stabilization → Gravity Thickening → Vacuum Filtration → Landfill
Alternative 2 - Lime Stabilization → Gravity Thickening → Vacuum Filtration → Landspreading
Alternative 3 - Lime Stabilization → Gravity Thickening → Pressure Filtration → Landfill
Alternative 4 - Lime Stabilization → Gravity Thickening → Pressure Filtration → Landspreading
Alternative 5 - Lime Stabilization → Gravity Thickening → Landspreading
Alternative 6 - Lime Stabilization → Landspreading

Since the national sedimentation sludge had such a high initial solids concentration, a gravity thickening step was not included in the calculations. Detailed capital and operation costs per process are included in the Appendix. Tables 42 to 45 summarize the annual costs for the different national acreages and the Milwaukee River Basin area.

The data indicate several trends. Landfill disposal is significantly less expensive than landspreading for all areas and treatment alternatives evaluated. The difference is most apparent when the solids content of the sludge is highest. The least costly alternative appears to be alternative No. 3 which involves lime stabilization followed by thickening (if needed), pressure filtration and then landfill disposal.

Figure 9 presents the range of annual costs per acre for the different areas evaluated. The annual costs for the Milwaukee River Basin were considerably less than nationwide costs. This is due to the much lower percent solids in the sludge caused by the lower concentration of solids in the influent UR. Since most of the capital costs for sludge handling equipment are based on solids loadings, the resultant annual costs were affected. This again illustrates the importance of evaluation on a site-specific basis.

TABLE 42. ANNUAL COSTS FOR SLUDGE HANDLING IN AN AVERAGE URBAN RUNOFF AREA (7,850 acres)

	Sedimentation		Swirl concentration	
Alternative	Total cost, $	$/acre	Total cost, $	$/acre
1	645,500	82.23	552,200	70.34
2	736,900	93.78	703,200	89.58
3	606,970	77.32	395,900	50.43
4	681,600	86.82	615,200	78.37
5	-	-	593,400	79.59
6	620,000	78.98	3,440,700	438.31

Metric conversions:

acres x .405 = ha

TABLE 43. ANNUAL COSTS FOR SLUDGE HANDLING A MEDIUM URBAN RUNOFF AREA (15,000 acres)

	Sedimentation		Swirl concentration	
Alternative	Total cost, $	$/acre	Total cost, $	$/acre
1	1,109,400	73.96	1,067,800	76.19
2	1,406,100	93.74	1,271,700	84.78
3	1,020,700	68.05	961,430	64.10
4	1,324,300	88.29	1,141,800	76.12
5	-	-	1,370,000	91.33
6	1,526,700	101.74	9,827,900	655.19

Metric conversions:

acres x .405 = ha

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TABLE 44. ANNUAL COSTS FOR SLUDGE HANDLING IN A LARGE URBAN RUNOFF AREA (30,000 acres).

	Sedimentation		Swirl concentration	
Alternative	Total cost,$	$/acre	Total cost,$	$/acre
1	2,144,000	71.46	1,850,400	61.68
2	2,941,500	98.05	2,306,700	76.89
3	1,683,700	56.12	1,533,920	51.13
4	2,188,600	72.95	1,925,800	64.19
5	-	-	2,546,700	84.89
6	2,904,800	96.83	19,718,900	657.30

Metric conversion:
acres x .405 = ha

TABLE 45. ANNUAL COSTS FOR SLUDGE HANDLING IN THE MILWAUKEE RIVER BASIN AREA (26,597 acres)

	Sedimentation		Swirl concentration	
Alternative	Total cost,$	$/acre	Total cost, $	$/acre
1	734,300	27.61	651,100	24.48
2	791,800	29.76	699,800	26.31
3	629,940	23.57	564,100	21.21
4	661,700	24.88	600,000	22.56
5	856,111	32.18	944,400	35.51
6	1,212,700	45.60	9,794,100	368.24

Metric conversion:
acres x .405 = ha

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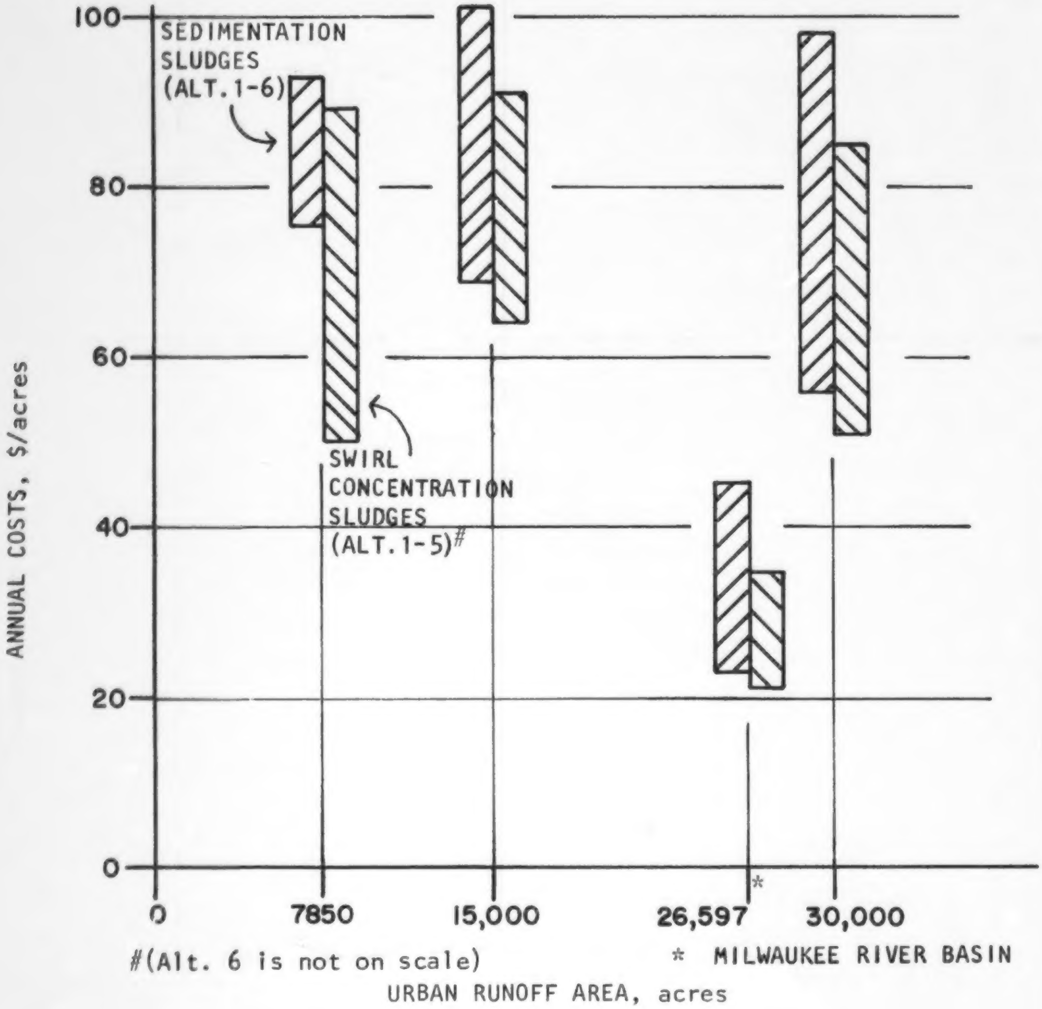

Figure 9. UR sludge disposal costs by area.

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Figure 9 also indicates that swirl concentration sludges are less expensive to handle than those generated from sedimentation processes. This can also be explained by the fact that additional solids are removed during sedimentation, (60 percent removals for swirl concentrations versus 87 percent removals for sedimentation). Since there is a significantly greater weight of solids generated for sedimentation, the associated sludge handling costs are greater. The difference exceeds the extra costs created by handling a more dilute swirl concentration sludge. This trend may not continue when in-depth cost analyses are performed.

In general, the annual handling costs on a dollars per area served basis were quite consistent for all area sizes. There was a large range of costs presented which reflected the variation in alternative handling techniques. The only completely inappropriate handling technique was alternative 6 for handling swirl concentration sludges. Due to the dilute nature of these materials and the associated high hauling costs, this alternative (lime stabilization followed by landspreading) was 5 to 10 times more costly than the others. This value is not reflected in Figure 9.

Average annual costs per area served and ranges are summarized in Table 46. The average annual cost indicates a small amount of economy of scale for the large UR area. However, in general, most ranges overlap.

TABLE 46. AVERAGE COST COMPARISON FOR UR SLUDGE HANDLING

	Sedimentation, $/acre		Swirl concentration, $/acre	
Area served	Range	Average	Range*	Average
7,850	77.32-93.78	83.83	50.43-89.59	73.66
15,000	68.05-101.74	85.16	64.10-91.33	95.06
30,000	56.12-98.05	79.08	51.13-84.89	67.76
26,597**	23.57-45.60	36.72	21.21-35.51	26.01

* Not including alternate 6.
** Milwaukee River Basin
acres x .405 = ha

The total capital costs are included in the Appendix. These are summarized in Table 47. The national costs ranged from $365 to $1390/ha ($148 to $563/acre) depending on the UR treatment method and the area served. Because of the larger volume of sludge being stored, swirl concentration sludge required somewhat higher capital expenses. Milwaukee River Basin costs were again susbstantially lower, for all alternatives, ranging from $168 to $743/ha ($68 to $301/acre).

TABLE 47. SUMMARY OF CAPITAL COSTS FOR VARIOUS AREAS

Sedimentation: area	Capital cost, $\$ \times 10^{-3}$	\$/acre
7,850	1,489 - 3,010	190 - 383
15,000	2,535 - 4,296	169 - 286
30,000	4,295 - 7,111	143 - 237
26,597*	1,810 - 3,068	68 - 115

Swirl Concentration Treatment: area	Capital cost, $\$ \times 10^{-3}$	\$/acre
7,850	1,972 - 3,988	251 - 508
15,000	3,248 - 8,439	217 - 563
30,000	5,242 - 15,907	175 - 530
26,597*	2,275 - 8,007	86 - 301

* Milwaukee River Basin
Metric conversion:
acres x .405 = ha

Land Area Requirements

The other primary impact which must be considered is the land area which will be required by the various sludge handling processes. Due to anticipated shortages of available land, this impact may be quite critical when assessing the effects of satellite sludge handling.

Basis of Land Area Calculations--
A final evaluation of land area requirements for all process units is site-specific. However, for estimating purposes, it is possible to approximate the area needed for various sludge handling units. The assumptions are summarized in Table 48 and discussed in the following paragraphs.

Storage volumes were estimated assuming an average volume and tank depth of 6.1 m (20 ft). The lime stabilization was anticipated to occur in the storage tank since this process had to be accomplished within 24 hours. Typical gravity thickener loadings of 122 $kg/m^2/day$ (25 $lbs/ft^2/day$) were assumed. A maximum thickener diameter of 18.3 m (60 ft) or approximately 260 m^2 (2,800 ft^2) was utilized. Area requirements exceeding this amount necessitated multiple units of equal diameter.

TABLE 48. BASIS FOR CALCULATION OF SLUDGE HANDLING PROCESSES LAND AREA REQUIREMENTS

Storage - 20 ft deep tank
Handles entire volume of sludge generated in 24 hours
Lime stabilization in this tank

Gravity Thickening - Loading - 25 lbs/ft^2/day (48)
Maximum diameter - 60 ft

Vacuum Filter - Loading - 8 lbs/ft^2/hr (22)

Pressure Filter - Chemical Dosing - 100 lb $FeCl_3$/ton sludge (48)
200 lb lime/ton sludge

Loading - 100 ton/day/unit
Size - 500 ft^2/unit
Additional equipment - double area needs

General - Add 20% for additional equipment

Metric conversions:
ft x .305 = m
lb x 0.454 = kg
tons x 0.908 = metric tons

Dewatering areas were quite different for the two methods. Vacuum filters were sized assuming a loading of 39 kg/m^2/hr (8 lbs/ft^2/hr). Once the filter area was established, it was scaled up to reflect various additional equipment including vacuum pumps, filtrate receivers, tubs, conveyors, etc. (22). Filter press loadings were assumed to be 91 metric ton/day/unit (100 ton/day/unit) for a large 130 chamber press which occupied 47 m^2 (500 ft^2) (48). The smaller sizes were scaled from this value. The press area was doubled to account for additional equipment needs.

Land area requirements were established for landspreading using the assumptions outlined in Table 40. Landfill area was estimated based on a loading rate for dewatered sludge of 1374 metric ton/year/ha (613 tons/year/acre).

Land Area Need for Various Sludge Handling Processes

The urban land area requirements for the various sludge handling options are presented in Table 49. For sedimentation treatment, solids handling area requirements ranged from .032 to .13 m^2/ha (0.14 to 0.57 ft^2/acre) of UR area. Swirl concentration sludge handling values were significanlty higher due to the larger volume of sludge to be stored on site. These requirements were calculated to be 0.41 to 0.48 m^2/ha (1.80 to 2.10 ft^2/acre) on a national basis and 0.22 to 0.45 m^2/ha (0.95 to 1.97 ft^2/acre) for the Milwaukee River Basin.

TABLE 49. LAND AREA REQUIREMENTS FOR SLUDGE HANDLING SYSTEMS

	Land area requirements, ft^2	
	Sedimentation	Swirl concentration
Alternative #1: Sedimentation + Gravity Thickening → Disposal		
UR Area, acres		
7,850	1,110	14,100
15,000	2,200	27,600
30,000	4,260	55,600
26,597*	6,000	25,200
Alternative #2: Sedimentation + Gravity Thickening + Vacuum Filtration → Disposal		
UR Area, acres		
7,850	4,500	16,500
15,000	7,800	31,100
30,000	13,400	62,000
26,597*	8,550	52,400
Alternative #3: Sedimentation + Gravity Thickening + Pressure Filtration → Disposal		
UR Area, acres		
7,850	1,600	14,500
15,000	3,100	28,300
30,000	6,100	56,900
26,597*	6,400	25,500

* Milwaukee River Basin
Metric conversion:
acres x .405 = ha
$ft^2 \times 0.0929 = m^2$

It can be assumed that the sludge handling facilities associated with storage/sedimentation can be located above the storage basin. Accordingly, these processes will not require any additional urban area. The same situation cannot be assumed when swirl concentration treatment is utilized.

The only significant area requirement is associated with the sludge handling equipment. These requirements are significantly less than the storage area needs since they range from 0.0042 to 0.0048 percent of the UR area on a national basis. Milwaukee requirements were less, ranging from 0.0022 to 0.0045 percent of the acreage.

SECONDARY IMPACT EVALUATION

The final evaluation of urban sludge handling methods requires a thorough study of the secondary, as well as the primary impacts associated with these procedures (49). Secondary impacts are extremely site-specific and most cannot be quantified except at a general level. However, the planner must take these into consideration when evaluating the overall impact of handling UR sludges. The following paragraphs address some of the potential secondary impacts. Where possible, some simple calculations have been included, however, most of the descriptions are, by necessity, qualitative in nature.

The secondary environmental impacts can be divided into three types: 1) those associated with the treatment system, 2) those associated with transportation of the sludge to a disposal site and 3) those associated with the disposal site. From the standpoint of UR sludge handling, the last type has the most significant secondary impacts.

On-Site Sludge Handling Treatment Facilities

When the on-site sludge handling facilities are implemented, there is a reduction in area availability, increases in energy use and higher noise levels. One secondary impact which becomes more critical is the nuisance associated with odor problems. The sludge should be stabilized within 24 hours in order to minimize odor problems, but this nuisance may still cause complaints in residential areas. Although difficult, if not impossible to quantify, the design must take this into consideration by providing relatively fast sludge stabilization, eliminating storage of non-stabilized sludge or grit,on-site,and reducing the time of on-site sludge storage prior to disposal.

Transportation

The environmental impacts associated with sludge transportation are also difficult to quantitate. The specific neighborhood in which the treatment facility is to be located must be evaluated from the standpoint of truck accessibility. Secondary environmental impacts of increased truck transportation include energy consumption, air pollution, and noise.

The amount of increased fuel consumption is dependent on the distance from the UR site to the disposal facility, the number of sites, the frequency of trips, and the type of truck used for sludge hauling. The economics of this have been calculated, but the increased use of energy, however small, can have long range impiications. For example, assuming that a gravity thickened, stabilized sludge is hauled 32 km (20 miles) from a 3,179 ha (7,850 acres) city, to a field for landspreading, then annual requirements of number 2 fuel oil are approximately 110,332 ℓ (29,150 gal). If filtered sludge is hauled the same distance to a landfill or field, the fuel requirements would be 46,366 ℓ (12,250 gal), or less than half.

Air pollution impacts include the increased emissions associated with the greater number of miles driven by a vehicle, as well as dirt and dust generation. The nuisance value of truck traffic on gravel roads can be extensive especially when the travel is of high frequency. Control of dust and dirt can be costly, depending on the logistics of the haul distance.

Noise pollution which can be attributed to increased traffic on the roads is not a major problem, but can be a nuisance and result in citizen complaints.

Other secondary impacts, not environmental in nature, include the availability of trucks, wear on access roads, safety of neighborhood residents when the traffic is increased, etc. These socio-economic factors must also be considered in a total evaluation.

Disposal Secondary Impacts

Both landfill and landspreading have associated secondary impacts. Most can only be addressed on a very general basis because quantification of the actual impacts is site-specific or not possible due to lack of necessary information.

Landfill--

Secondary impacts associated with disposal by landfill include water and air pollution plus an assortment of other considerations (50).

Landfill area--Probably one of the most critical impacts is the increased area required for disposal of UR sludges. For an average UR area of 3,179 ha (7,850 acres), a typical dry-weather sludge volume at 20 percent solids is 250 m^3/day (0.066 Mgal/d). UR sludges can add 49 to 212 m^3/day (0.013 to 0.056 Mgal/d), depending on the dewatering method. This represents an increase of 19 to 85 percent. With the difficulties associated with licensing landfills near urban areas, the increase in rate of use is especially critical. When the landfill area requirements are calculated, there is an increase of approximately 14 to 18 percent needed when UR sludge is landfilled along with the dry-weather plant sludge. Therefore, cities which utilize landfill for sludge disposal would be out of space sooner if additional UR sludge disposal was required.

Water pollution--Proper operation of a landfill can minimize or eliminate both surface and ground-water pollution, but the potential for water quality degradation still exists if the location/operation is inappropriate. Factors such as soil conditions, ground-water depth, surface water proximity, cover material, covering procedures, amount of rainfall, and standing water, can all impact the potential water pollution associated with a disposal site.

Ground water can be contaminated by sludge leachate. For example, a sanitary landfill handling municipal refuse can produce a leachate with the following qualities (57):

Components	Range of all values, mg/ℓ	Components	Range of all values, mg/ℓ
Alkalinity ($CaCO_3$)	0-20,850	Nitrogen-NH_3	0-1,106
BOD (5 day)	81-33,360	Nitrogen-Kjeldahl	0-1,416
Calcium	60-7,200	Nitrogen-NO_3	0.2-10.3
COD	40-89,520	Potassium	28-3,770
Copper	0-9.9	Sodium	0-7,700
Chloride (Cl^-)	4.7-2,467	Sulfate ($SO_4^=$)	1-1,558
Hardness ($CaCO_3$)	0-22,800	TDS	584-44,900
Iron - Total	0-2,820	TSS	10-700
Lead	<0.1-2.0	Total Phosphate	0-130
Magnesium	16.5-15,600	Zinc	0-370
Manganese	0.09-125	pH	3.7-8.5+

Leachates from UR sludges may have lower concentrations of nutrients but may still contain significant amounts of metals and trace organics. Proper control of leachates will be required and may necessitate a separate collection and treatment system. Surface water contamination can involve almost any type of pollution, depending upon the site, type of water, and sludge.

Increase in vectors--Nuisance vectors associated with a landfill site include birds, rodents, flies and other insects. These cause extreme public reactions. Increasing the amount of sludge landfilled increases the possibilities of vectors. This may be more critical if grit or sludge is not stabilized before disposal.

Noise and air pollution--Depending upon the proximity of the site to residents, problems with both noise and air pollution may be encountered. Air pollution is associated with dust generation on access roads, as well as emissions from landfill machinery. The operation of the site could result in complaints regarding noise since much of the heavy equipment used in the operations could be objectionable to neighboring residents.

Sensitive/unique areas--Depending upon the site location, there may be problems associated with impacting a unique or sensitive environmental area. These could be marshlands, parks, wildlife sanctuaries, etc. The impact could involve the location of the present site, location of access to the site or need for new sites after the present location is filled.

Landspreading--

Many of the impacts associated with landspreading are similar to those associated with landfill.

Area requirements--As with landfill, the more sludge to be disposed of, the sooner the site is exhausted. Since landspreading rates are controlled by various constituents of the sludge, the relationships are not related to the volume as much as to the concentration of metals and nutrients in the sludge. However, in all instances, disposal of UR sludge can add significant land area needs to a specific site.

The average availability of land for landspreading disposal is limited, especially in close proximity to a large urban area. This area may be more readily purchased than landfill sites, however, more land is required. The fact remains that in a time when disposal sites of all kinds are limited, adding more residues to those requiring disposal involves a significant secondary impact.

Water pollution aspects--There are both surface and ground-water pollution. threats from a land application site, as well as a landfill. The ground water can be affected by seepage or leaching from the sludge storage areas. Runoff from sites which have been recently used for disposal could be contaminated with coliforms, as well as with significant amounts of BOD and SS. These impacts can be controlled by a combination of proper design, operation and monitoring procedures (51).

Soil impacts--Soil can be either positively or negatively impacted by landspreading procedures. The contaminants can be concentrated in the soil which could be detrimental to other land uses. On the other hand, the organic content of sludges could help soil. This latter effect is less prevalent with UR sludges, however, because of the low concentrations of volatile solids already present in the sludge. It should be mentioned that lime present in stabilized sludges can be helpful to certain soil types.

Uptake of toxic materials--A significant secondary impact of landspreading can be the uptake of various toxic materials by crops. There are conflicting reports about the extent of the uptake and the long term effects. For this report, it is sufficient to note that this impact must be carefully evaluated and minimized by proper application rates and crop regulations.

Noise and air pollution--These types of impacts can also be increased by the same types of factors discussed for landfill.

SECTION 8

LAND DISPOSAL OF STORM GENERATED SLUDGES

This section is concerned with the evaluation of completed and on-going work on land disposal of domestic/industrial waste sludges which will lead to the formulation of specific R&D recommendations for land disposal of wet-weather flow sludges. Moreover, answers to the following questions will be derived from the ensuing discussion:

> Can wet-weather flow sludges be incorporated into dry-weather flow land disposal programs? If no, why not? If yes, are there any problems? What can be done to make incorporation applicable? Is there enough information to formulate an opinion? If no, what has to be done?

DEFINITIONS

1. Storm-generated or wet-weather sludges are sludges generated from the treatment of UR and CSO.
2. Domestic sludges are those obtained from dry-weather municipal treatment plants.
3. Industrial sludges are waste solids resulting from industrial processing and/or from waste treatment operations,and may be generally classified as organic, chemical or metal sludges.
4. Land utilization of sludges involves the disposal of sludges on land, or utilizing land application or landfilling methods.
5. Land application of sludge involves spreading wastewater solids on the soil surface.
6. Sludge landfilling can be generally defined as the burying of sludge, i.e., the application of sludge to the land,and subsequent application of a soil cover.

Can Wet-Weather Flow Sludges be Incorporated Into Dry-Weather Flow Land Disposal Programs?

The EPA sludge management research and development program encompasses four major technical areas, namely, (a) processing and treatment, (b) utilization,

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(c) disposal and, (d) health and ecological effects. The primary objective of the program is to develop new and improved technology and management schemes which will enable communities to solve problems associated with the residues or byproducts of wastewater treatment in a cost-effective and environmentally acceptable manner (52).

It may be seen from the above description of the EPA sludge management programs, that generally, the wet-weather flow sludges fall into the primary EPA program objectives and can be incorporated into dry-weather sludge land disposal and land utilization programs. However, there are foreseeable problems, which are not insurmountable, associated with such an incorporation, and these are related to the inherent differences between dry-and wet-weather sludges. Some of the pertinent problems are discussed below.

LAND REQUIREMENTS

The disposal of wet-weather sludges by land utilization will require more land than that needed for land utilization of dry-weather sludges alone. For example, the expected annual volumes of dry-weather sludges generated are:

Sludge	Annual sludge volume 10^6 m^3	Annual sludge volume 10^9 gal	Average percentage solids
Dry weather (17)	125.0	33.0	2-3
Combined sewer overflow (11)	157.0	41.5	0.3-6
Urban runoff (Table 21)	8.8-175.0	2.3-45.5	0.5-12

It is apparent from the above table that the gross magnitude of the combined volume of wet-weather sludges generated is up to twice that of the dry-weather sludges. It should also be pointed out that the dry-weather sludge solids are available for disposal on a relatively continuous basis (say, during 60 storm events per year). Moreover, although the dry-weather and UR sludges are distributed relatively uniformly throughout the United States, the distribution of combined sewers in the United States is concentrated in the Northeast and Great Lakes regions of the country. Therefore, it is further indicated that the separate and codisposal of dry and wet-weather sludges will probably be a more formidable land requirement problem in the Northeast and Great Lakes Region of the United States.

Land utilization of sludges may be accomplished by (a) land application, or (b) landfilling. Germane to this discussion are the land requirements (land application rates) for the two land utilization methods.

Using the land application method, two distinct application rates can be considered depending upon the system objectives:

1. To recycle nutrients or apply sludge at agricultural rates, the nitrogen or heavy metal loadings will usually limit the application

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rates (53).

2. Higher loadings can be used when (53):
   a. Detailed monitoring of environmental impacts is conducted
   b. Uses such as reclamation of strip-mined land or application to forests or sod are considered.
   c. Non-food chain crops are grown on the site.

The lower agricultural application rates for crop production are calculated in the same manner as commercial fertilizer. In this regard, dry-weather sludges are considered a low grade fertilizer. Furthermore, a 22.4 metric ton/ha/yr (10 ton/acre/yr) rate for sewage sludge is a realistic first approximation for application to agricultural soils. UR and CSO sludges, in comparison (Table 21), may be considered even lower grade fertilizers. Comparison of heavy metal concentrations were dependent upon urban street-sweeping practices and industrial wastes in the sewage, among other factors. Therefore, metal analyses for site-specific sludges should be made to determine if metal concentrations are limiting for agricultural applications.

The literature has indicated that the utilization of both sewage sludge and animal waste would require 1.3 percent of the cultivated land in the U.S.(53), therefore, any concern about supply of land to utilize fully the increasing quantities of sewage sludge and animal waste being generated annually may be unwarranted. This is a further indication that wet-weather sludges can be incorporated into EPA sludge land disposal and land utilization programs.

As mentioned previously, higher land application rates may be employed for non-agricultural uses, such as forested lands, parklands, highway median strips, and the reclamation of damaged or poor terrain (53). The advantage of utilizing sludge for non-agricultural uses is that metal loadings may not limit application rates, however, the impact of cumulative metal additions in the ecosystem will have to be assessed. For example, thought will have to be given to minimizing metal toxicities, to allow growth of other crops on the soils in question if the area were cleared at a future date. Land utilization of sludges may also be accomplished by landfilling. Land-filling methods include narrow and wide trenching, area fill mound and layer, co-disposal with refuse and soil, diked containment, etc. Sludge and site conditions as well as design criteria are available for each method. It has been recommended (53) that pilot-scale testing be performed to ensure that operation based on the criteria used will function properly for a given sludge and site. Sludge application rates vary with the landfilling method used and range from 2,436 m^3/ha (1,290 yd^3/acre) (at 15 percent solids) to 26,000 m^3/ha (13,770 yd^3/acre) (at 32 percent solids). Assuming a sludge specific gravity of 1.25, the application rates would vary from 457 metric ton/ha (204 dry ton /acre) to 10,389 metric ton/ha (4,640 dry ton/acre). It may be seen that the sludge application rates, utilizing landfilling, are appreciably greater than those for land application. All other things being equal, land requirements for landfilling would be appreciably less than those for land application.

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PRETREATMENT REQUIREMENTS

Pretreatment involves those processes that prepare the sludge for ultimate disposal, and will influence the transport mode from the treatment site to the land utilization site. The purpose of pretreatment is to overcome problems due to pathogens, odor, operation, and costs.

For land utilization of wet-weather sludges, preapplication treatment of the sludges is similar to that for dry-weather sludges and includes:

1. Storage
2. Thickening
3. Stabilization
4. Dewatering

Minimum pretreatment is required, of course, if the wet-weather sludges could be utilized on the land in liquid form. For landfill applications, liquid sludge is not suitable, and dewatering of sludge to a minimum of 15 percent solids for disposal in sludge-only landfills is indicated (53). For land application purposes, liquid sludge disposal is desirable, but is generally cost-effective for relatively short distances (8 to 16 km (5 to 10 miles)) from the treatment plant. In addition, even when wet-weather liquid sludge land application is suitable, a minimum storage requirement is needed. The reason for this is that liquid sludge should not be applied to wet soils during or immediately after heavy rainfall because compaction and reduced crop yields result, and muddy soils make vehicle operation difficult.

It may be concluded from the above discussion that liquid wet-weather sludge will see limited use. This report on UR sludges and a previous one (11) on CSO sludges have indicated that the most applicable pretreatment processes for handling wet-weather sludges are storage, thickening, lime stabilization, and dewatering. However, these treatment processes have not, to date, been demonstrated on wet-weather sludges at either a pilot or full-scale level.

COSTS

Cost for the land utilization of wet-weather sludges may be determined in a manner similar to that for municipal sludges as the cost elements involved are similar, namely, preliminary planning, preapplication treatment and transport, site selection and acquisition, etc. (53).

Although costs for land utilization of wet-weather sludges have been estimated in this report and others (11), these costs should be used for preliminary work only, as actual cost may vary considerably with specific local conditions.

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SECTION 9
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APPENDIX

TABLE A-1. COST ESTIMATES BY PROCESS FOR AVERAGE AREA (7,850 ACRES) WITH SEDIMENTATION TREATMENT

Process	Costs, dollars Capital	 Operating and maintenance	 Annual
Storage	187,000	--	17,700
Pumping	610,000	25,040	82,600
Lime stabilization	244,000	57,040	80,100
Vacuum filtration	1,290,000	127,520	249,000
Centrifugation	1,180,000	131,270	243,000
Pressure filtration	1,690,000	76,774	237,000
Hauling:			
After lime stabilization	160,700	191,600	216,050
After vacuum filtration	88,600	83,750	94,870
After pressure filtration	94,600	63,250	74,930
Landfilling:			
After vacuum filtration	110,000	24,500	37,000
After pressure filtration	95,000	24,000	35,500
Landspreading:			
After lime stabilization	287,900	53,400	142,705
After vacuum filtration	188,600	40,100	115,895
After pressure filtration	184,430	28,000	100,325

Metric conversion: acres x 0.405 = ha

TABLE A-2. COST ESTIMATES BY PROCESS FOR AVERAGE AREA (7,850 ACRES) WITH SWIRL TREATMENT

	Costs, dollars		
Process	Capital	Operating and maintenance	Annual
Storage	380,000	--	35,815
Pumping	501,000	21,900	69,200
Lime stabilization	203,000	39,800	59,000
Gravity thickening	515,000	12,300	61,000
Vacuum filtration	1,300,000	101,800	226,000
Centrifugation	850,000	100,200	180,800
Pressure filtration	1,290,000	58,800	180,300
Hauling:			
After lime stabilization	983,450	1,756,000	1,927,250
After gravity thickening	155,200	158,400	182,300
After vacuum filtration	94,600	63,250	74,900
After pressure filtration	88,100	49,250	60,300
Landfilling:			
After vacuum filtration	95,000	24,000	35,500
After pressure filtration	84,500	23,800	34,800
Landspreading:			
After lime stabilization	1,920,000	534,540	900,680
After vacuum filtration	168,850	28,000	85,540
After pressure filtration	127,030	19,800	69,371
After gravity thickening	218,300	43,750	108,680

Metric conversion: acres x 0.405 = ha

TABLE A-3. COST ESTIMATES BY PROCESS FOR MEDIAN AREA (15,000 ACRES) WITH SEDIMENTATION TREATMENT

Process	Costs, dollars Capital	 Operating and maintenance	 Annual
Storage	358,000	--	33,800
Pumping	813,000	31,660	108,400
Lime stabilization	350,000	109,000	142,000
Vacuum filtration	2,030,000	124,540	316,400
Centrifugation	1,630,000	238,100	392,600
Pressure filtration	2,240,000	123,400	334,400
Hauling:			
After lime stabilization	422,000	613,750	685,900
After vacuum filtration	197,400	289,000	318,600
After pressure filtration	159,300	206,250	229,500
Landfilling:			
After vacuum filtration	165,000	28,500	45,500
After pressure filtration	128,000	25,700	39,500
Landspreading:			
After lime stabilization	592,040	102,000	357,000
After vacuum filtration	427,700	75,400	303,500
After pressure filtration	375,820	53,100	271,000

Metric conversion: acres x 0.405 = ha

TABLE A-4. COST ESTIMATES BY PROCESS FOR MEDIAN AREA (15,000 ACRES) WITH SWIRL TREATMENT

	Costs, dollars		
Process	Capital	Operating and maintenance	Annual
Storage	570,000	--	53,725
Pumping	718,000	28,600	96,400
Lime stabilization	298,000	76,950	105,100
Gravity thickening	813,000	19,800	96,600
Vacuum filtration	1,490,000	164,700	305,400
Centrifugation	1,190,000	174,800	287,400
Pressure filtration	1,900,000	100,700	280,000
Hauling:			
After lime stabilization	3,226,700	5,937,500	6,528,100
After gravity thickening	367,000	501,900	564,200
After vacuum filtration	159,300	208,250	231,500
After pressure filtration	122,200	150,625	167,700
Landfilling:			
After vacuum filtration	130,000	25,800	39,800
After pressure filtration	107,500	24,200	36,500
Landspreading:			
After lime stabilization	3,626,400	1,006,880	1,762,650
After vacuum filtration	320,100	53,100	217,130
After pressure filtration	271,600	38,000	193,350
After gravity thickening	482,100	83,700	275,255

Metric conversion: acres x 0.405 = ha

TABLE A-5. COST ESTIMATES BY PROCESS FOR LARGE AREA (30,000 ACRES) WITH SEDIMENTATION TREATMENT

	Costs, dollars		
Process	Capital	Operating and maintenance	Annual
Storage	718,000	--	67,800
Pumping	1,160,000	40,300	150,300
Lime stabilization	576,000	218,000	272,200
Vacuum filtration	3,800,000	336,400	694,500
Centrifugation	2,370,000	417,900	642,000
Pressure filtration	2,980,000	206,300	488,000
Hauling:			
After lime stabilization	741,000	1,204,000	1,334,000
After vacuum filtration	305,000	556,000	604,000
After pressure filtration	236,500	392,250	428,300
Landfilling:			
After vacuum filtration	310,000	42,500	75,500
After pressure filtration	225,000	34,000	57,500
Landspreading:			
After lime stabilization	1,100,300	203,000	701,650
After vacuum filtration	552,300	152,000	550,930
After pressure filtration	499,000	106,500	496,565

Metric conversion: acres x 0.405 = ha

TABLE A-6. COST ESTIMATES BY PROCESS FOR LARGE AREA (30,000 ACRES) WITH SWIRL TREATMENT

	Costs, dollars		
Process	Capital	Operating and maintenance	Annual
Storage	950,000	--	39,540
Pumping	990,000	39,300	132,700
Lime stabilization	474,000	154,300	199,100
Gravity thickening	1,310,000	32,300	156,4 0
Vacuum filtration	2,850,000	276,400	545,000
Centrifugation	2,030,000	316,000	508,000
Pressure filtration	2,510,000	161,500	398,000
Hauling:			
After lime stabilization	6,317,400	12,046,000	13,214,345
After gravity thickening	635,400	987,500	1,098,200
After vacuum filtration	236,500	392,250	428,300
After pressure filtration	197,400	289,000	318,600
Landfilling:			
After vacuum filtration	228,000	34,000	58,000
After pressure filtration	165,000	28,500	39,500
Landspreading:			
After lime stabilization	7,175,540	2,011,100	3,511,155
After vacuum filtration	562,540	106,400	454,800
After pressure filtration	508,440	75,500	380,300
After gravity thickening	882,540	167,500	538,600

Metric conversion: acres x 0.405 = ha

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TABLE A-7. COST ESTIMATES BY PROCESS FOR THE MILWAUKEE RIVER BASIN AREA WITH SEDIMENTATION TREATMENT

Process	Costs, dollars		
	Capital	Operating and maintenance	Annual
Storage	380,000	--	36,150
Pumping	360,000	22,500	58,365
Lime stabilization	220,000	41,175	61,140
Gravity thickening	550,000	10,700	63,140
Vacuum filtration	1,260,000	109,200	228,160
Pressure filtration	1,355,000	61,500	189,400
Hauling:			
After lime stabilization	422,950	609,000	681,200
After gravity thickening	260,400	356,200	399,240
After vacuum filtration	121,200	138,500	155,440
After pressure filtration	88,100	91,000	102,070
Landfilling:			
After vacuum filtration	150,000	24,100	36,100
After pressure filtration	88,000	23,800	34,900
Landspreading:			
After lime stabilization	427,320	121,875	217,690
After vacuum filtration	162,480	36,060	86,100
After pressure filtration	114,900	23,640	65,100
After gravity thickening	265,560	59,400	126,410

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TABLE A-8. COST ESTIMATES BY PROCESS FOR THE MILWAUKEE RIVER BASIN AREA WITH SWIRL TREATMENT

	Costs, dollars		
Process	Capital	Operating and maintenance	Annual
Storage	590,000	--	55,640
Pumping	430,000	20,000	60,930
Lime stabilization	169,000	29,300	45,300
Gravity thickening	450,000	10,800	53,000
Vacuum filtration	1,250,000	87,000	204,700
Pressure filtration	1,200,000	49,800	162,360
Hauling:			
After lime stabilization	3,277,500	6,037,500	6,637,500
After gravity thickening	312,250	401,700	454,240
After vacuum filtration	88,100	100,500	111,570
After pressure filtration	88,100	68,000	79,070
Landfilling:			
After vacuum filtration	92,000	23,900	35,000
After pressure filtration	81,000	23,600	34,200
Landspreading:			
After lime stabilization	3,541,325	1,056,950	1,717,200
After vacuum filtration	124,350	27,400	77,365
After pressure filtration	121,120	15,760	65,415
After gravity thickening	323,900	67,520	152,100

TABLE A-9. SUMMARY PROCESSES - CAPITAL COSTS (dollars)

Alternative flow scheme*	Sedimentation UR area served, acres 7,850	15,000	30,000	Milwaukee
1) Sed → LS → GT → VF → LF	2,529,600 (322)	3,913,400 (261)	6,869,000 (229)	3,041,000 (114)
2) Sed → LS → GT → VF → LA	2,608,000 (332)	4,176,000 (278)	7,111,300 (237)	3,053,700 (115)
3) Sed → LS → GT → PF → LF	2,920,600 (372)	4,048,300 (270)	5,895,500 (197)	3,041,000 (114)
4) Sed → LS → GT → PF → LA	3,010,000 (383)	4,296,000 (286)	6,169,500 (206)	3,068,000 (115)
5) Sed → LS → GT → LA	1,489,600 (190)	2,535,000 (169)	4,295,300 (143)	2,036,000 (77)
6) Sed → LS → LA	--	--	--	1,810,300 (68)
	Swirl UR Area served, acres 7,850	15,000	30,000	Milwaukee
1) Sed → LS → GT → VF → LF	3,088,600 (393)	4,178,300 (279)	7,038,500 (235)	3,069,000 (115)
2) Sed → LS → GT → VF → LA	3,162,500 (403)	4,368,400 (291)	7,373,000 (246)	3,111,500 (117)
3) Sed → LS → GT → PF → LF	3,061,600 (390)	4,528,700 (302)	6,596,400 (220)	3,008,000 (113)
4) Sed → LS → GT → PF → LA	3,104,000 (395)	4,693,000 (313)	6,940,000 (231)	3,048,000 (117)
5) Sed → LS → GT → LA	1,972,500 (251)	3,248,000 (217)	5,242,000 (175)	2,275,000 (86)
6) Sed → LS → LA	3,988,400 (508)	8,439,000 (563)	15,907,000 (530)	8,007,000 (301)

* Key:

Sed = Sedimentation
VF = Vacuum filtration
LS = Lime stabilization
PF = Pressure filtration
GT = Gravity thickening
LA = Land application
LF = Landfill

** Numbers in parentheses are dollars per acre.

Metric conversion: acres x 0.405 = ha